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ERRATA

- Page 209, line 18, for " salix " read "*Salix* "
- Page 252, lines 6 and 7 from end, for " fuschin " read " fuchsin "
- Page 328, line 10, for "*Tineola furcifuella* " read "*Tineola furciferella* "
- Page 395, line 11, for " and could safely " read " and could all safely "
- Page 491, line 10, for " 29 " read " 28 "
- Page 645, line 2 of title, for " Curtis " read " (Curtis) "
- Page 723, line 7, for " CULICINAE " read " CULICIDAE "
- Page 775, line 13 from end, for " Unitel " read " United "
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COMMONWEALTH INSTITUTE OF ENTOMOLOGY.

BULLETIN

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1956.

THE SUSCEPTIBILITY OF FOURTH-STAGE LARVAE OF *ANOPHELES GAMBIAE* TO DDT AND DIELDRIN.

By M. CHRISTIE and G. WEBBE

Entomologists, Medical Department, Tanganyika Territory.

Trapido (1951) has drawn attention to the desirability of establishing a standard against which the susceptibilities of the important malaria vectors of the world to modern synthetic insecticides can be assessed. His investigations were concerned with larval response: a similar approach to the questions of the levels of response of the adult mosquitos has been advocated by the Expert Committee on Malaria of the World Health Organisation (1954).

It was considered that an investigation of the type described by Trapido (*l.c.*) into the level of response of *Anopheles gambiae* Giles to DDT and dieldrin would be of value for three reasons:—

1. Practical experience of larval control with DDT gained on the American continent could be applied with greater confidence to African conditions if the relative susceptibilities of the vector species were known.
2. A standard would be established against which suspected resistance could be tested at any future date.
3. An indication of the order of dosage of dieldrin required in field practice would be obtained.

In this investigation the use of the term Minimum Lethal Dose has been retained. The Minimum Lethal Dose is here defined as the lowest dose proving fatal to all individuals exposed to it, as determined approximately by inspection and rough interpolation. It is not an exact concept and its retention is clearly open to criticism. In the first place the term is unfortunate, both in its similarity to the invalid concept of Minimal Lethal Dose (Finney, 1952, p. 17), and also in its abbreviation, MLD, entailing possible confusion with the Median Lethal Dose. Secondly, its retention may appear to involve a wasteful neglect of the technique of probit analysis which is now freely available for use by biologists without specialised training in statistics (Finney, 1952).

Initial testing, and research into the mechanism of an insecticide in the laboratory, obviously call for the use of the more accurately determinable LD₅₀.

and the probit-log dosage regression line calculated from data in the region of the LD50. On the other hand, operators of a control programme are interested in dosages that will produce 100 per cent. kill, provided that they fall within economic limits, and, as Finney (1952, p. 222) remarks: "Though the normal distribution is usually adequate to explain the dose-response relationship for a considerable range on either side of the 50 per cent. response, there is rarely any certainty that it is correct, and, if the true probit regression equation has a slight curvature, extrapolatory estimation of a dose such as the LD99* might be grossly misleading." Unfortunately, at the time of conducting these experiments the authors did not have access to the second edition of Finney's work, where the problem of estimating the LD99 by the method of inverse sampling is discussed.

It may still be maintained that, practical considerations apart, the most accurate method of detecting the development of resistance will be by the established methods of probit analysis. Where two populations of insects (of the same, or different species) show a difference at the LD50, there can be no doubt that their responses to the insecticide differ in some respects. However, Busvine & Harrison (1953) have reported a situation in which two populations of the same species that do not differ significantly at the LD50, give regression lines of significantly different slope which diverge beyond the LD50. The reverse situation in which the regression lines converge beyond the LD50 might equally well occur. In the first case, where there is no difference at the LD50, there will be a considerable difference in the dosage of insecticide required to produce 100 per cent. kill, whereas the standard methods of probit analysis are concentrating attention on a level of mortality at which the populations do not differ in their response. In the second, hypothetical, case of regression lines convergent beyond significantly different LD50's, the point of crossing will be important: it is conceivable that the population recorded as more susceptible by the LD50 method might require the greater quantity of insecticide for its complete extermination.

The arguments of simplicity and relevance give considerable support to the use of the frankly imprecise measure of the Minimum Lethal Dose determined by simple inspection, rather than the precisely determinable LD50 which bears a doubtful relation to the quantity to be estimated.

Acetone Suspensions of DDT and Dieldrin in Water.

The method used followed that of Trapido (1951) closely, a description is only given where details differed.

Wild-caught females of *A. gambiae* were obtained from native houses in the region of Muheza, Tanganyika (lat. 5°10' S., long. 38°45' E.) and taken to the laboratory in Amani where oviposition took place. Larvae were reared in enamel pans in an insectary maintained at a temperature of $27 \pm 1^\circ\text{C}$. The larvae were fed on commercial canned bakers' yeast, added to the pans as an aqueous suspension. All fourth-stage larvae present in the pans were removed night and morning, only the morning collection being used in the experiments. The fourth-stage larvae tested were thus never more than twelve hours old in that stage. In place of the 400 ml. beakers described by Trapido, cut down 32 oz. bottles were used. The acetone solutions of insecticide used in preparing the suspensions were measured out with an "Agla" microsyringe. The accuracy of delivery of this instrument (± 0.0005 ml.) made it possible to prepare a wide range of suspensions from a single stock solution of the insecticide. Acetone (0.5 ml.) was added to the controls, a greater quantity of solvent than was received by any of the test jars. As the local tap-water contained large quantities of colloidal matter

* The term actually used in the passage quoted is ED99, ED representing *effective dose*, a more general term including responses other than death. Ed.

which might have absorbed insecticide, 240 ml. of aerated distilled water were measured into each jar, and 10 ml. of a solution of salts (CaSO_4 1 part, NaCl 1 part, MgSO_4 2 parts) were added to give a total concentration of dissolved solids of 160 parts per million. Mortality was measured after 48 hours, those larvae failing to respond to the touch of a needle being counted as dead. Larvae which pupated during the course of the experiment (0.04% of total larvae) have been omitted from the calculations of mortality.

The DDT used in the preparation of the suspensions was a technical grade. A sample was drawn at the time of preparing the suspensions, and an analysis was undertaken by Dr. J. Robinson of the Colonial Insecticide Research Unit, Arusha. The p.p' content was found to be 81.8 per cent. For convenience in tabulation the p.p' content has been taken as 80.0 per cent. The dieldrin was a recrystallised preparation of 100 per cent. purity supplied by Messrs. Shell Chemicals Ltd.

Results.

The results of these experiments with acetone suspensions are set out in Table I.

TABLE I.

Forty-eight-hour mortality of early fourth-stage larvae of *Anopheles gambiae* exposed to acetone-water suspensions of DDT and dieldrin.

Concentration of insecticide (Parts of water to 1 part insecticide)	Percentage kill	
	DDT	Dieldrin
12.5 million	(9) 100	
25		(3) 100
31	(13) 96.9	
50	(2) 82.5	(3) 100
62	(11) 69.9	
100		(7) 99.3
125	(4) 14.0	
200		(7) 87.8
250		(3) 85.0
300		(9) 50.0
400		(5) 53.0
500		(8) 18.9
750		(2) 7.5
Controls	(5) 0.0	(5) 2.0
Controls with acetone ..	(7) 1.0	(8) 2.5

The figures in brackets denote the number of replicates, each of 20 larvae.

From these results it is concluded that the 48-hour MLD for acetone-water suspensions of DDT to *A. gambiae* is about 1 part of DDT in 15 million parts of water. This shows that *A. gambiae* resembles *A. claviger* (Mg.) (Trapido, 1951), and is some 20 times as resistant as *A. quadrimaculatus* Say throughout the greater part of the range of the latter species. The MLD for acetone-water suspensions of dieldrin is in the neighbourhood of 1 part of dieldrin in 90 million parts of water. It is interesting to compare the toxicities of DDT and dieldrin. These results give a toxicity figure of approximately 6 for dieldrin compared with DDT as 1, with *A. gambiae*, whereas Keller, Davis & Mooney (1951), making the

comparison at the level of the LC50, found a value for dieldrin of only 2.8 with *A. quadrimaculatus*. Ginsburg (1950), working with *Aedes aegypti* (L.), found a value of 4.2 for dieldrin at the LC50 and 7.5 at the 100 per cent. mortality level. The data presented in the present paper were not designed for an estimation of the regression lines. However, if regression lines are fitted by eye, the lines for DDT and dieldrin appear to be nearly parallel, suggesting that, even at the LC50, the relative toxicity of dieldrin to *A. gambiae* is still approximately 6, and is therefore appreciably higher than to *A. quadrimaculatus*.

Oil Solutions of DDT and Dieldrin.

The experiments described above give data for an adequate comparison of the response of *A. gambiae* with other species. It might also be reasonably assumed that appearance of resistance in field populations would show itself in a change of the response of larvae to acetone-water suspensions of the insecticides. Resistance, however, may be due either to changes in the efficiency of detoxication processes, or in the rate of penetration of insecticides into the body of the insect. As DDT is used in larval control in an oil solution it was considered desirable to make comparable estimates of the response to oil solutions and, at the same time, to compare the performance of dieldrin in oil solutions and suspensions with regard to the design of suitable formulations for field use.

In tests involving oil films of insecticides on an aqueous surface it is essential to ensure that the spread of the oil is complete and even. The most reliable method of obtaining an even spread of an oil film is for a stream of water to be run into a funnel arrangement from below, thus permitting any surface active material to be floated off before the oil is applied.

Funnels were made for this purpose from the top half of 32 oz. bottles. The details of construction are shown in fig. 1. The neck was filled with plaster of

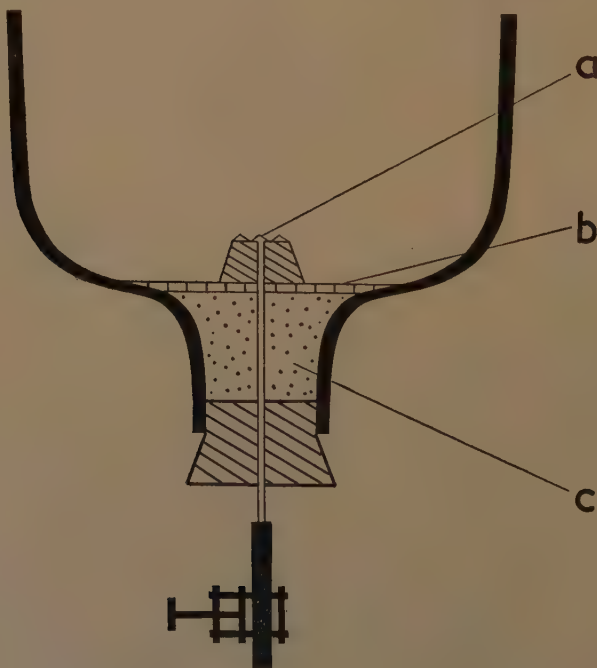


Fig. 1.—Showing apparatus used for experiments with oil solutions:—
a, mosquito gauze; b, layer of cellulose paint; c, plaster of paris.

paris in order to block out the recess in which larvae might have become trapped. Wooden racks were made to hold six of the funnels. At the start of the experiment the forefinger was rubbed on a block of soap and run round the inside of the funnel, ensuring detergence of any surface active materials such as grease from the hands which might have interfered with the free spreading of the oil, the water supply connected and water run over the edge for a short time. The water was then turned off and a quantity of water spilled out so as to leave the level 2 in. below the rim of the funnel. The insecticide was dissolved in kerosene, with 2 per cent. of blown fish oil added to ensure complete spreading. The appropriate strength of solution was applied with an "Agla" microsyringe, so as to give an oil dosage in every case at the rate of one quart per acre. Immediately before applying the oil the larvae were driven to the bottom by invoking the shadow reaction, in order to avoid direct "oiling". Controls received exactly similar treatment with solvent only.

Conditions of rearing, and the temperature maintained during the experiments were as in the series with acetone-water suspension.

Results.

The results are set out in Table II. A high degree of consistency in the method is indicated by the results marked with an asterisk, which were obtained in a second series of experiments conducted four months after the first. The dosages given in Table II refer to pure dieldrin and 100 per cent. p,p' DDT.

TABLE II.

Forty-eight-hour mortality of early fourth-stage larvae of *Anopheles gambiae* exposed to oil films of DDT and dieldrin.

Dosage (lb./acre)	Percentage mortality	
	DDT	Dieldrin
0.05	(8) 100	
0.03	* (5) 100	
0.021	* (5) 100	
0.0156	* (21) 99.5	
0.015		(10) 100
0.0125	* (7) 98.0	
0.01	(26) 95.5	
0.005	(11) 93.1	
0.0025	(15) 87.5	
0.0015		(40) 100
0.00125		* (9) 100
0.00104		* (8) 100
0.00083		* (11) 99.1
0.00080		* (7) 96.4
0.00077		(52) 96.8
0.00051		(18) 85.5
0.00038		(16) 81.3
0.00031		(14) 79.7
Controls	(7) 1.4	(21) 1.7
(with oil)	* (9) 0.5	* (14) 2.1

Quantity of oil constant at rate of 1 quart per acre of water surface.
Figures in brackets denote the number of replicates, each of 20 larvae.

* Second series of experiments.

These figures show that the MLD for oil films of dieldrin is approximately 0.001 lb./acre and 0.02 for DDT, a toxicity ratio of 20:1. Support for the indication given by these results, namely that the greater toxicity of dieldrin in acetone-water suspensions is still further enhanced when acting in oil solutions, has been obtained in a further series of experiments to be reported at a later date.

Summary.

The validity of the MLD (Minimum Lethal Dose) as a practical concept for measuring toxicity, despite its obvious lack of precision, is discussed. Its use has justification.

The 48-hour MLD of acetone-water suspensions and oil films of DDT and dieldrin for early fourth-stage larvae of *Anopheles gambiae* Giles have been measured.

The results show *A. gambiae* to be relatively resistant to DDT.

In acetone-water suspension dieldrin appears to be about six times as toxic as DDT. In oil solutions this difference is more marked, the ratio being in the neighbourhood of 20:1.

Acknowledgements.

These results are published with the permission of the Director of Medical Services, Tanganyika Territory.

We wish to thank Dr. J. Robinson for the Colonial Insecticide Research Unit, Arusha, Tanganyika, for analysing the sample of DDT, and Messrs. Shell Chemicals Distributing Company of Africa Ltd., for the supply of blown fish oil and dieldrin.

References.

- BUSVINE, J. R. & HARRISON, C. M. (1953). Bull.ent.Res., **44**, pp. 729-738.
FINNEY, D. J. (1952). Probit analysis.—2nd edn., 318 pp. Cambridge Univ. Pr.
GINSBURG, J. M. (1950). Shell agric. Bull., no.ADB 228, 1 p.
KELLER, J. C., DAVIS, A. N. & MOONEY, C. I. (1951). Mosq. News, **11**, pp. 171-174.
TRAPIDO, H. (1951). J.nat.Malar. Soc., **10**, pp. 266-271.
WORLD HEALTH ORGANISATION. (1954). Tech. Rep. World Hlth Org., no. 80, 42 pp.
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BIOLOGY AND ECOLOGY OF THE GARDEN CHAFER, *PHYLLOPERTHA HORTICOLA* (L.).

I.—THE ADULT AND EGG PRODUCTION.

By A. MILNE* and R. LAUGHLIN*

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Newcastle upon Tyne.*

A number of Scarabeid larvae, collectively known as "white grubs", are extremely important pests of grassland and certain crops (ranging from corn to coconuts) throughout the British Commonwealth. Britain herself suffers little from white grubs. Here, the worst pest is the Garden Chafer, *Phyllopertha horticola* (L.), which can devastate pasture as a larva and defoliate fruit trees as an adult. But the Garden Chafer is by no means a countrywide problem. Most records of damage come from south and south-west England, Wales, the Lake District and west Scotland. Even in those areas severe damage is very localised in any year, by far the greater part of the countryside suffering negligibly or not at all (see maps of damage in Thomas & Heal, 1944, and in Gray, Peet & Roger-son, 1947). This is no consolation, however, to the farmers on whose land the severe damage actually occurs.

The broad, bare outlines of the annual cycle of the Garden Chafer in Britain have been known for a long time: the adults appear above ground in May or June and lay their eggs in the soil, the larvae feeding on plant roots until winter hibernation in the third instar, the hibernation giving way directly to a prepupal followed by a pupal stage in spring. Raw (1951) reviews previous British work briefly but pertinently as follows: "The early investigators were concerned primarily with the control of *P. horticola* by means of insecticides and repellents. The biology and ecology of the insect received little attention. In the more recent work of Thomas & Heal, and Gray, attention has still been focussed on control and economic importance, but some advance has been made in understanding the relationship between the insect and its environment. Their work emphasises the need for further study of this relationship." Raw himself (1951) concentrated more on, and made considerable advances in, the biology and ecology; indeed his was the first really substantial contribution. He points out, nevertheless, that much of his work "is of necessity exploratory, serving rather to break the ground and reveal those aspects of the problem which would repay further study, than providing a detailed investigation of particular points."

In late 1947 a small section of the Agricultural Research Council Unit of Insect Physiology began a long-term study of the biology and ecology of the Garden Chafer in the Lake District. As well as meeting a local need, this project had the added attraction that it concerned the chief British representative of a world-wide pest type. The present paper is the first of a series embodying the results of the investigation. It deals with the reproductive performance of the adult beetle in the laboratory (field data come later in the series). The work of Raw (1951) was repeated and extended using his techniques, viz., the 1 lb. jam jar with 2 mm. soil for oviposition and the practical tin with soil for incubation of eggs. Moistened plaster of paris blocks requiring no soil were latterly used for incubation.

* Agricultural Research Council Unit of Insect Physiology.

Effect of Adult Feeding on Egg Production.

Raw concluded from his jar experiments (p. 645, see also p. 616 and Table IV): "In general, feeding by the adult does not affect fecundity but in one experiment beetles fed on salad burnet [*Poterium sanguisorba*] produced and laid more eggs than beetles fed on grass, bracken or blackberry or kept without food." Raw's experiment was twice repeated using samples over three times as large and it was found that burnet had no such effect.

TABLE I.

Effect of different foods on fecundity and egg production.

Jar experiment	Group	Beetles fed on	No. of females	Mean fecundity	Mean egg production	No. of females laying	
						No eggs	All their eggs
2	A	Grass	40	12.4	14.3	6	21
2	B	Blackberry	40	11.6	14.0	3	24
2	C	Burnet	40	11.1	13.8	6	23
2	D	No food	40	10.9	14.8	7	23
8	A	Burnet	41	15.5	17.0	4	27
8	B	Bracken	41	13.0	17.6	7	17
8	C	No food	41	13.5	15.5	6	30

In one experiment, four groups of females gave the results shown in Table I (jar experiment 2). Obviously feeding has no effect either on fecundity (number of eggs laid) or on egg production (number laid plus number left in oviducts at death). Analyses of variance gave variance ratios of less than 1 for both fecundity and egg production. The other experiment (see Table I, jar experiment 8) told the same story though the variance ratios were slightly higher (for fecundity $F = 1.428$, for egg production $F = 1.998$; 5% value with 2 & 80 d.f. = 3.11).

Raw's result was probably a freak of chance. One factor contributing towards the high fecundity and egg production in his burnet group is the absence of barren females (*i.e.*, females laying no eggs) in this group alone. His other groups had 1, 2, 2 & 3 barren females respectively. Even one barren female in a group of 12 can reduce the figure for mean egg production very considerably. Another unusual feature of Raw's burnet group is that every female laid all her eggs. This too, was probably a freak result; there is no indication of a similar effect in large experimental groups (Table I).

Raw showed, in two jar experiments, that starved adults produce and lay as many eggs as fed adults. This has been confirmed in a further four experiments where the mean and range of pupal weight were as similar as possible in starved and fed groups. All the data available for the six experiments are shown in Table II. The ranges for egg production are given as 0 to 32 and 0 to 33 but the occurrence of females incapable of producing any eggs at all is most unlikely. Beetles producing no eggs are invariably very short lived and contain fat-body at death; they would have utilised the fat-body for egg production had they lived longer. It is obvious that there is no difference between the means for fed and

starved females ($P = 0.40$ for fecundity and $P = 0.10$ for egg production). It follows, as Raw pointed out, that the egg production of the female depends entirely on the stores laid down by the larva before hibernation. This fact has a good deal of significance in the ecology of the Garden Chafer.

TABLE II.

Effect of starvation on fecundity and egg production.

	Fed	Starved
Number of females ..	311	153
Mean fecundity	12.86	12.31
Range (fecundity) ..	0 - 32	0 - 32
Mean egg production ..	15.73	14.90
Range (egg production) ..	0 - 33	0 - 32

The comparison of starved with fed beetles is a useful technique for the physiologist and a number of other differences were found which will be given below. In nature, however, food is always available to adults so that adult starvation effects are, in themselves, irrelevant to the beetle's ecology.

Length of Adult Life.

Table III shows all the available data for the length of life of fed females in jam jars at room temperature in May and June. Raw's third experiment(*)

TABLE III.

Length of life (days) of fed female Garden Chafers in oviposition jar.

Source	Number of females	Length of life (days)		Datum line for measurement
		Range	Mean	
Raw, Table I (omitting Nos. 6-9)	18	16 - 28	19.9	C + ? days
Raw, Table II (Batch mated 20.v.46)	12	19 - 29	23.8	B + ? days
Raw, Table III* (Group A)	17	3 - 21	10.5	B + ? days
Jar experiment 1	24	3 - 33	18.4	B
Jar experiment 2	80	6 - 32	20.8	A
Jar experiment 5	40	10 - 38	25.4	A
Jar experiment 8	134	3 - 29	17.1	A

Datum lines as follows: A. The splitting of the pupal skin.
 B. The attainment of full pigmentation.
 C. The primary emergence above ground into activity.

* See text.

seems to be aberrant. For some reason, probably a spell of hot weather during the experiment, every process was speeded up to about twice the rate in other experiments. Setting the aberrant data aside, the average female has an expectation of about three weeks from the moulting of the pupal skin to death. Individual lives range from three days to as much as five weeks.

Starvation shortens the life by a day or two (Table IV). In jar experiment 8 the mean lengths of life for 82 fed and 41 starved females were 15.6 and 13.5 days, respectively. The difference of 2.1 days is significant ($P = 0.01$). In jar experiment 2, on the other hand, 120 fed females (3 groups of 40 fed on grass, blackberry and burnet, respectively) and 40 starved females gave mean lengths of life of 20.1 and 18.8 days respectively. This difference is not significant ($P = 0.1$).

However, there are grounds for believing that even in experiment 2 starvation had its effect. Figures for each group are shown in Table IV. Notes were taken

TABLE IV.

The effect of adult feeding on the length of life.

Jar experiment	Number of females	Females fed on	Length of life (days)		Standard deviation
			Range	Mean	
2	40	Grass	7 - 25½	18.6	4.62
2	40	Blackberry	7½ - 28	20.5	4.35
2	40	Burnet	6½ - 31½	21.1	5.89
2	40	No food	9½ - 24	18.8	3.43
8*	41	Burnet	3 - 29	15.7	5.15
8	41	Bracken	4 - 26	15.5	4.67
8	41	No food	6 - 19	13.5	3.69

* In jar experiment 8 there was also another group of 52 burnet-fed females (mean length of life, 19.5 days) making a total of 134 fed females in the whole experiment (see Table III). This group cannot be considered in the comparison above since the beetles came from a different population.

during the experiment to discover when and how much food was eaten. The beetles in the grass group were never seen feeding nor did the grass appear to have been chewed. It may be therefore, that this was effectively a starved group, refusing the food they were offered. If now we compare the grass group plus the no food group (mean 18.7 days) with the two groups known to have been feeding (mean 20.8) the difference in length of life is significant ($P = 0.01$).

There is some doubt as to whether starvation (lack of both food and water) or dehydration is the major cause of the small starvation effect. The jars of unfed beetles, containing only sifted soil and twigs, are noticeably drier than those of the fed beetles. However, comparing the grass group with the no food group (Table IV), it seems likely that this dryness is relatively unimportant. The grass group can perhaps be regarded as a starved group in which the humidity

in the jars is similar to that in the fed groups. Yet the grass group beetles live no longer than those in the drier "no food" jars.

Of the male, Raw (1951) says: "in laboratory experiments with pairs of adults, it was found that the male usually dies before the female and often needs to be replaced a second or third time before the female dies." Our finding is not in agreement. Comparing the lengths of life of males and females (Table V)

TABLE V.

The length of life of males and females.

Jar experiment	Group	Mean length of life in days	
		Male	Female
1	A	19.5	20.2
1	B	16.0	16.1
1	C	22.3	22.9
4	—	23.9	26.9

The death precedence in jar experiment 1 was as follows:—in Group A the male died first in 5 jars and the female first in 4 whilst both died about the same time in 3; the corresponding figures for Group B were 6, 4 and 2, respectively.

we find no significant difference between them. Even the difference of three days in jar experiment 4 is not significant ($P = 0.1$). The death precedence in groups A and B of jar experiment 1 (where the male and female in each jar were of the same age) is also shown (under Table V) and gives no support to Raw's statement.

Some mated females lay no eggs; the proportion in any sample varies from 0 to 35 per cent., mean 14 per cent. (see Table VII). A major cause of this barrenness is indicated by the distribution of female life lengths (fig. 1). Oviposition started about 14 days after ecdysis (range 9 to 24 days) while females started dying off at 6 days. Twenty two females were barren and had a mean length of life of 11.8 days (range 6 to 21 days), 17 of them dying before the 14th day. The females which laid eggs had a mean length of life of 21.0 days (range 12.5 to 31.5).

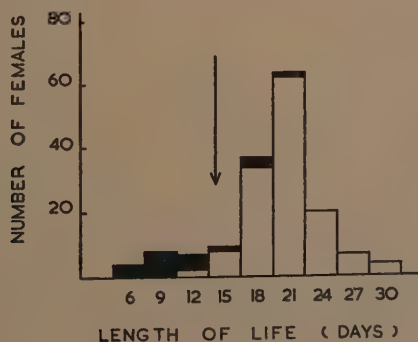


Fig. 1.—Frequency distribution of females according to length of life. Black columns indicate barren females and arrow shows mean age at which oviposition started.

Similarly, of the 60 females in jar experiment 5, 51 started to lay eggs at 18.9 days (range 14 to 27). The mean length of life of the nine barren females was 19.3 days (range 9 to 34).

Thus, a majority of the barren females are those which have died before they are ready to lay their eggs. A shift in the relative positions of the mortality histogram and the start of oviposition, quite a likely event in the field, could have a large effect on the percentage of barren females and thus on the reproductive rate of the population. This suggestion will be discussed in relation to field data in a later paper.

Time Patterns in the Female Adult Life.

The following data were obtained from dissection of females kept at 15°C. At ecdysis the ovaries contain no full-size eggs. At most there is one oocyte visible as a small swelling at the base of each ovariole. The abdomen is full of fat-body. At 10 to 15 days the fat-body is gone and the ovaries and oviducts are packed with full-size eggs, with perhaps one or two immature eggs left in the ovarioles. The average female, if given the opportunity to mate as soon as she is inclined, starts laying eggs about 13 days after ecdysis (range, 8 to 24 in 208 females). Thus, the evidence suggests that, under laboratory conditions at least, females do not begin to lay eggs until the ovaries have finished or nearly finished egg manufacture. This point was investigated thoroughly in the field (see later paper).

Females start to feed about the beginning of the oviposition period and thereafter take food every day they are above ground.

The oviposition period, *i.e.*, the time elapsing between the laying of the first and last eggs, for the average female is 5.4 days (range 1 to 23, see Table VI). Data on the distribution of the oviposition period among 29 females from Raw, Table IIIA and jar experiment 4, the only experiments in which the jars were examined daily, showed that 16 females had an oviposition period of 1 to 3 days,

TABLE VI.

Duration of oviposition period, *i.e.*, days elapsing between the laying of first and last eggs in individual females.

Source of data	Number of females laying eggs	Duration of oviposition period (days)	
		Range	Mean
Raw, Table I ..	22	1 - 14	4.9
Raw, Table II ..	32	1 - 23	6.3
Raw, Table III A ..	17	1 - 16	5.4
Jar experiment 1 ..	8	1 - 19	9.4
Jar experiment 2 ..	71	1 - 17	4.9
Jar experiment 3 ..	12	1 - 12	4.3
Jar experiment 4 ..	32	1 - 18	5.2
<i>In toto</i> : ..	194	1 - 23	5.4

3 of 4 to 6 days, 4 of 7 to 9 days and 3 each for 10 to 12 and 13 to 16 days. Visual inspection of Raw's Table III shows, as might be expected, that females laying more eggs generally have a longer oviposition period. Actually the correlation is very highly significant, *e.g.*, $r = 0.5617$, $t = 6.259$ for 85 d.f. for the 87 fertile females in Raw's Tables I-III.

Of the duration of life, after oviposition has ended, Raw merely says that the females "died soon after the last eggs were laid". Further information from 71 females (from Raw, Tables I, II and IIIA) showed that 44 females were dead 0 to 2 days after the end of oviposition, 16 after 3 to 5 days, 9 after 6 to 8 days and 2 after 9 to 11 days, giving a mean period of 2.4 days (range 0 to 10).

The above data all refer to fed females because there appears to be some difference between the oviposition periods of fed and starved females. Raw (1951, p. 617 and Table III) found that fed females took longer to lay their eggs. The results from jar experiments 2 and 5 show the same effect: in jar experiment 2 the 71 fed females laid eggs over a mean period of 4.9 days (range 1 to 17) and the 67 starved females over a mean period of 3.5 days (range 1 to 10). The difference of 1.4 days is significant ($P = <0.01$). In jar experiment 5, 18 fed and 18 starved females took averages of 4.3 and 2.1 days respectively to lay their eggs (ranges 1 to 16 and 1 to 4 respectively). This difference, 2.2 days, is also significant ($P = 0.03$).

Although probably a female seldom fails to meet a male in nature, it is perhaps interesting to compare the data for mated females with a random sample of 12 females kept singly in jars and not mated. They began to feed at the same time as mated females of the same age. Nine died without laying eggs and the three which did oviposit laid only 2, 4 and 6 eggs, respectively, on the last day of life (approximately 3, 4 and 5 weeks, respectively, after ecdysis). Naturally none of these eggs was viable.

Number of Eggs laid.

There is now a considerable amount of data on the number of eggs laid in jar experiments. The combined data of Raw's four experiments and seven of ours show that 644 females laid a total of 8,275 eggs (mean 12.85, range 0 to 46). The 644 females may well be considered a random sample from a fairly wide range

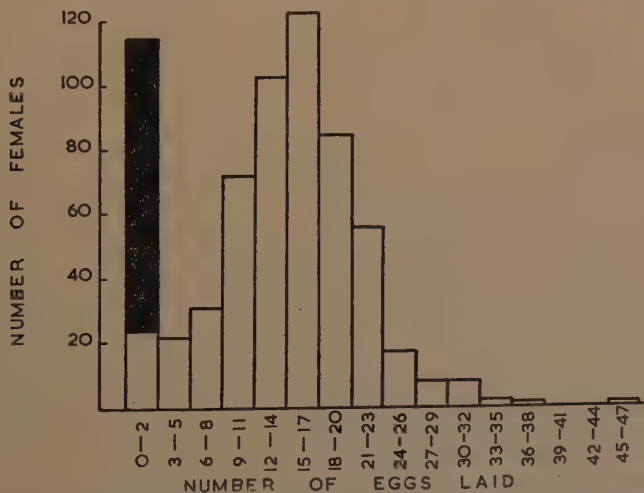


Fig. 2.—Frequency distribution of females according to the total number of eggs laid. Black column indicates barren females.

of natural conditions (Table VII). The frequency distribution of these females, according to the number of eggs they laid, is shown in fig. 2. If the barren females (14%) are excluded, the distribution is of the normal (slightly skewed) type common in nature.

TABLE VII.

The number of eggs laid by individual females.

Source of data	No. of ♀♀ in sample	No. of eggs laid		No. of barren ♀♀	Barren females %
		Range	Mean		
Raw, Table I (1945) ..	22	1 - 33	13.3	0	0.0
" " II (1946) ..	38	0 - 46	14.5	6	15.8
" " III A (1947) ..	17	1 - 32	13.4	0	0.0
" " III B (1947)* ..	20	0 - 32	11.4	4	20.0
" " IV (1948) ..	12	0 - 29	9.8	3	25.0
" " " " " " ..	12	0 - 29	12.2	2	16.7
" " " " " " ..	12	5 - 25	17.3	0	0.0
" " " " " " ..	12	0 - 22	11.4	2	16.7
" " " " " " ..	12	0 - 25	11.9	1	8.3
Jar experiment 1 A (1948) ..	12	0 - 29	11.8	4	33.3
" " 1 B (1948)* ..	12	0 - 23	12.4	2	16.7
" " 2 A (1949) ..	40	0 - 32	12.4	6	15.0
" " 2 B (1949) ..	40	0 - 23	11.6	3	7.5
" " 2 C (1949) ..	40	0 - 20	11.1	6	15.0
" " 2 D (1949)* ..	40	0 - 22	10.9	7	17.5
" " 4 (1950) ..	24	0 - 30	10.1	6	25.0
" " 5 A (1950) ..	20	0 - 31	14.2	1	5.0
" " 5 B (1950)* ..	20	0 - 20	13.0	1	5.0
" " 5 C (1950) ..	20	0 - 26	11.4	7	35.0
" " 6 (1952) ..	20	10 - 30	19.6	0	0.0
" " 6 (1952) ..	24	0 - 24	11.4	5	20.8
" " 8 A (1953) ..	41	0 - 28	15.5	4	9.8
" " 8 B (1953) ..	41	0 - 28	13.0	7	17.1
" " 8 C (1953)* ..	41	0 - 24	13.5	6	14.6
" " 8 D (1953) ..	52	0 - 30	13.4	8	15.4
Totals	644	0 - 46	12.85	91	14.1

* Starved as adults.

As mentioned on p. 9, the number of eggs produced by the female depends entirely on the amount of fat-body in the hibernating larva. It may be seen from Table X that, before dying, only a minority (28%) of females have not laid all or nearly all of the eggs they produced.

The reason why a female which has started to lay eggs should not lay them all is not clear. It seemed likely that the commonest cause would be death before oviposition could be completed, especially when it was found that, in jar experiment 2, females with eggs left at death lived for a significantly shorter time than those which had laid all their eggs ($P = 0.01$). However, the difference was not significant in jar experiment 8 ($P = 0.5$) and in Table VIII the mean lengths of life of the different classes of female show no tendency towards short life in females laying only a small proportion of their eggs, except in the barren females which have already been discussed (p. 12).

It occurred to us that perhaps conditions in the experimental jars were such that some females refused to lay all their eggs. Examination of a collection of beetles found dead on the grass at Buttermere, however, suggested that residual eggs occurred to about the same extent in nature. Thus of 25 females collected,

15 (60%) contained no eggs and the other 10 contained a total of 66 eggs, mean 6.6 (range 1 to 21). In jar experiment 2, 57 per cent. contained no residual eggs and the mean number of eggs found in the other females was 6.3 (range 1 to 20). In jar experiment 8, 62 per cent. contained no residual eggs and the mean number found in the other females was 7.3 (range 1 to 24).

TABLE VIII.

Frequency distribution of fecundity, expressed as a percentage of total eggs produced.

Fecundity/egg production (percentages)	0 (barren females)	1 - 20	21 - 40	41 - 60	61 - 80	81 - 100
Number of females ..	47	11	6	13	16	242
Mean length of life (days)	10.2	15.0	21.3	18.2	17.4	19.5
Mean weight of pupa (mg.)	164.8	166.5	153.5	167.2	161.6	166.1

Data from jar experiments 2 & 8 (335 females).

Effect of Body Weight.

Raw (1951) found highly significant positive correlations between fecundity and the weight of the hibernating larva, the pupa and the adult. Our data confirm the existence and significance of these correlations for egg production as well as fecundity. Both sets of correlations are statements of the obvious. As seen above (p. 9), egg production (and thus fecundity) depends mainly on the stores laid down by the larva. It is to be expected, therefore, that heavier individuals will be capable of producing more eggs. In jar experiment 2 (a random sample of 160 females) the regressions were $F = 0.113 W - 6.60$, $P = 0.150 W - 9.77$, where F = number of eggs laid (fecundity), P = number of eggs produced and W = weight of pupa in mg.

Raw points to "a significant positive correlation in Group A" (in his Table III) between body weight and length of life. The mean durations were 6.2 and 15.3 days for the 9 smaller and 8 larger females, respectively. This

TABLE IX.

The weight of the pupa. Statistics from a random sample of 542 pupae collected in the field.

	Males	Females
Number in sample ..	327	215
Mean weight (mg.)	144.3	183.3
Range	90 - 196	105 - 245
Σx	47199	39404
Σx^2	6925479	7349138

correlation is not to be found anywhere else however, either in the rest of Raw's data or in our own. Indeed it would be surprising if larger females lived longer.

The mean and range of pupal weight in barren females and fecund females are compared in Table VIII. Clearly, weight has no influence on the occurrence of barrenness.

Individual pupal weights are approximately normally distributed in samples of either sex. Females are heavier than males, the statistics from a random sample of 542 pupae collected from the field being shown in Table IX. The average female is between 1.24 and 1.30 times heavier than the average male (fiducial limits for the 5% level of probability).

The extreme range in weight (mg.) of females in nature found in very large samples from different places in N.W. England over six years was:—

Hibernating larva	99-370
Pupa	80-310
Adult	31-127

Raw cites five heavier adults (128, 128, 129, 134 and 156 mg.).

The total egg production of the average female is of interest as an indicator of the extreme upper limit of the rate of population increase from generation to generation. For several obvious reasons this rate is, of course, never realised in nature. The average female weighs about 175 mg. as a pupa. Substituting this value in the appropriate regression formula above, she produces 16 eggs. Thus if all individuals always fulfilled themselves, a population would increase eight-fold annually.

TABLE X.

The numbers of eggs laid in the first and second halves of the oviposition period.

	Number of females laying :		
	More eggs in first half	Same in both halves	More eggs in second half
Table I	6	1	9
Table II	13	1	10
Table III	11	1	13
Total females	30	3	32

	Percentages of eggs laid in the two halves of the oviposition period where :			
	More eggs are laid in the first half		More eggs are laid in the second half	
	1st half	2nd half	1st half	2nd half
Table I	76.8	23.2	17.6	82.4
Table II	68.5	31.5	20.2	79.8
Table III	76.9	23.1	28.8	71.2

Data from Raw (1951) Tables I, II & III.

Oviposition Pattern.

In Raw's Tables I, II & III there are data for 97 females. Some or other parts of this data are suitable for making the various points below (assuming that, except for females 6-9 in Table I, all were mated when "they attained their full colour and just became active").

Ten females (10.5%) died without laying eggs. Fifteen females (15.5%) completed their oviposition within 24 hours of starting. They layed respectively 1, 1, 1, 1, 2, 2, 2, 8, 9, 9, 9, 10, 11, 17, and 27 (mean 7.3) eggs per female.

TABLE XI.

Distribution of eggs over the oviposition period in individual females.

Total eggs laid		Oviposition day															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
4	*	1	—	—	1	—	—	1	—	1	—	—	—	—	—	—	—
5	*	2	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—
6	***	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	***	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	**	6	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	***	2	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	***	1	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	*	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	***	3	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—
9	***	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	*	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	*	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	**	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	**	6	—	—	2	—	2	—	—	—	—	—	—	—	—	—	—
11	*	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11	**	4	2	5	—	—	—	—	—	—	—	—	—	—	—	—	—
12	***	11	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	***	10	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	***	2	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	*	10	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—
15	**	1	13	1	—	—	—	—	—	—	—	—	—	—	—	—	—
16	*	10	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—
17	**	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	***	15	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
17	**	4	4	9	—	—	—	—	—	—	—	—	—	—	—	—	—
18	*	2	—	—	16	—	—	—	—	—	—	—	—	—	—	—	—
18	**	5	6	1	—	6	—	—	—	—	—	—	—	—	—	—	—
19	**	3	12	4	—	—	—	—	—	—	—	—	—	—	—	—	—
20	***	1	4	—	15	—	—	—	—	—	—	—	—	—	—	—	—
20	**	1	—	—	—	—	—	3	—	2	—	—	—	6	1	6	1
21	*	3	—	—	18	—	—	—	—	—	—	—	—	—	—	—	—
21	*	5	—	—	—	—	—	16	—	—	—	—	—	—	—	—	—
22	**	10	—	11	—	—	—	—	—	—	—	—	1	—	—	—	—
23	**	1	—	1	2	11	—	—	—	—	—	—	—	1	1	—	6
25	***	10	12	—	2	1	—	—	—	—	—	—	—	—	—	—	—
26	*	7	—	—	19	—	—	—	—	—	—	—	—	—	—	—	—
26	***	4	—	5	10	7	—	—	—	—	—	—	—	—	—	—	—
27	*	27	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27	***	2	—	4	21	—	—	—	—	—	—	—	—	—	—	—	—
32	***	6	—	13	—	11	2	—	—	—	—	—	—	—	—	—	—
32	**	5	1	7	1	—	—	—	—	—	—	—	—	—	1	15	2

Data from Raw, (1951) Table II (marked *), Table III A (marked **) and Table III B (marked ***).

Note: Seven females laid less than 4 eggs. All seven laid their eggs within 24 hours.

The remaining 72 females (74.2%) took between 2 and 23 days (mean 5.7) to lay all their eggs, the totals of which ranged from 2 to 46 (mean 16.5) per female. Eggs laid per day varied from 0 to 25 (mean 6). In 65 of the cases the numbers of eggs laid in the first and second halves of the oviposition period are clearly shown, and may be tabulated as in Table X. Obviously there is no difference between the two halves of the oviposition period. Some lay more of their eggs in the first half while just as many lay more in the second half.

Among 87 females laying eggs, the data for 48 show what happened daily during the oviposition period (see Table XI). Apart from the tendency for a longer oviposition period to go with a larger total of eggs laid (see before), there seems to be neither rhyme nor reason about the distribution of eggs over the period. Four eggs were laid in 9 days in one instance whilst in another 27 took only 24 hours. The same number of eggs could take a longer or shorter time to lay in larger or smaller dribbles, the numbers of eggs and the intervals between them being apparently quite random. Raw's suggestion that "two distinct batches of eggs" are laid by some of the heavier females has little if anything to support it. Gray, Peet & Rogerson were right in claiming that only one series of eggs is laid. There is not the slightest evidence of a fixed oviposition pattern, which is rather important when it comes to interpreting events in the field.

The Location of Eggs in the Soil.

If she must, a female will lay all her eggs in an empty glass tube. When presented with soil she always lays below the surface. In the unnaturally loose and small soil particles of the experimental jars it is impossible to find out the normal behaviour of the egg-laying female. Eggs may even be found on the surface, disturbed by the female's later burrowings. An attempt was made to study oviposition in more natural conditions.

Just before oviposition commenced in the field, blocks of turf, 4 in. \times 4 in., were dug unbroken from pasture favoured by the Garden Chafer. The grass was sliced off each block at the surface of the soil. This left a dark smooth surface on which entrance holes would easily be seen. Each block rested in a closely fitting tin 2 in. deep, the bottom $\frac{1}{2}$ in. of which contained sand, for drainage. Thus $1\frac{1}{2}$ in. depth of naturally textured soil and herbage roots was provided, i.e., the normal medium for oviposition. Fertilised females, one per tin, were caged over the grassless turf. After a few days each block was turned out whole from the tin and pared carefully in thin slices with a knife to reveal the positions of the eggs. Whenever a live beetle was found near the eggs it was invariably in a nearly vertical position and head downwards; one wonders if this is the usual posture for oviposition.

No beetles entered the sand beneath the soil. The sand was very compact. A small proportion of eggs had been laid in cup-like depressions on the surface of the sand. The precise vertical location was ascertained with certainty for only 34 eggs: 31 were in the bottom $\frac{1}{2}$ inch of soil (8 on the sand surface and most of the remaining 23 in the $\frac{1}{4}$ in. above); two were in the middle $\frac{1}{2}$ in. and one in the top $\frac{1}{2}$ in. (about $\frac{1}{4}$ in. from the soil surface). Since this is probably rather less than half of a normal distribution curve, the soil in the tins was not deep enough to give a complete picture of vertical distribution in nature where soil is up to 6 in. deep. But several interesting facts were established from a study of 15 entrance burrows and their associated 60 eggs. The findings may be summarised thus:

- a) A female burrows down at a different point each time she has eggs to lay.
- b) At each burrowing she deposits her eggs within a radius of 1 in. at most from the vertical line passing through the entrance hole on the surface.
- c) If she has several eggs to lay at one burrowing they are all deposited apart

from one another. In any plane the least distance between eggs was $\frac{3}{16}$ in. and the greatest distance $\frac{3}{4}$ in. (average about $\frac{1}{4}$ in.).

d) Each egg is in an earthen cell which is 2 to 4 times the width of the unswollen egg. Rittershaus (1927) agrees that each egg is laid in a separate cavity.

Duration of Incubation.

At 18°C., Raw found eggs hatching in 20 to 30 days, mean between 22 and 25 days. Gray, Peet & Rogerson (1947) state: "Pot experiments were carried out in the open at Rydal in order to determine the incubation period of the eggs and the results corresponded, in the main, with observations made in the field. The weather at the time was somewhat cold and wet. The time elapsing between the laying of eggs and hatching in the field varied from 27 to 30 days." This 27 to 30 days is almost certainly an approximation of the *mean* time, not the range. No details are given as to the treatment of the pots, *e.g.*, whether sunk in the ground. Raw holds that his own "observations from field sampling . . . confirm those of Gray that it [the incubation period in nature] is approximately 28 days". Neither Raw nor Gray, Peet & Rogerson give any details of what happened in the field.

In the fluctuating temperature of the unheated field laboratory (a flimsy wooden structure) in 1948, eggs took 28 to 42 days to hatch in sufficiently moist soil. Maximum temperatures for the experimental eggs were on the average about 2°C. higher than in the pasture soil at $1\frac{1}{2}$ in. depth, minimum temperatures being about equal. The weather during the latter half of June and the first half of July was somewhat below average in temperature, but by no means cold, whilst before and after this period it was somewhat above average. Thus we may conclude that eggs in nature, under average conditions of soil temperature, take considerably more than 28 days to hatch on the average.

The mean duration of the incubation period at various constant temperatures is shown in Table XII. Around 15°C., a small change in temperature makes a big difference to the mean length of the incubation period, *viz.*, 40 days at 15°C. but only 29 days at 17°C. This is perhaps the explanation of the wide variation in estimates from field observation.

TABLE XII.

The length of the incubation period at constant temperature.

Temperature (°C.)	11	14	15	17	20	23	25	26
Incubation period (days)	86	42	40	29	21	18	14	13

Fertility.

Raw uses the term "fertility" to denote the proportion of eggs that hatch. The available data show that this proportion varies between 72 and 96 per cent. of the eggs laid by a group of females (Table XIII).

There is evidence that the eggs which fail to hatch comprise both unfertilised eggs and eggs which have been fertilised but die from other causes. The eggs are opaque-white and ovoid when laid; in the course of development they take up water and swell, becoming nearly spherical and of a pearly, translucent appearance after about one third of the incubation period. In the experiment mentioned on p. 13, eggs laid by virgin females did not even begin to swell.

Hence eggs laid by mated females which do not swell are probably infertile, while eggs which swell normally but fail to hatch are fertile, their failure to hatch being due to other causes, such as disease, fungus attacks, etc. In jar experiment 1, the 81 eggs which failed to hatch (28% of total eggs laid) consisted of

TABLE XIII.

The numbers of eggs which fail to hatch.

Source of data	No. of ♀♀	Total eggs laid	Eggs not hatching	Percentage hatch
Raw, Table III A ..	17	228	31	86.4
Raw, Table III B ..	20	227	13	94.3
Raw, Table IV ..	60	752	40	94.7
Jar experiment 1 ..	24	291	81	72.4
Jar experiment 2 ..	160	1838	142	92.3
Jar experiment 4 ..	24	242	24	90.1
Jar experiment 5 ..	60	771	71	90.9
Jar experiment 6 ..	64	768	30	96.1
Jar experiment 8 ..	175	2417	150	93.8

61 which did not swell, 14 which swelled a little and 6 which finished swelling but died later. Consequently the 28 per cent. of non-viable eggs is made up of 21 per cent. of infertile eggs and 7 per cent. of eggs dying from other causes.

Raw notes that "fertility" (i.e., viability) is related to the age of the female

TABLE XIV.

Total eggs, and their mortality, at intervals after the fully coloured stage was reached in 18 females.

	Days after full coloration			
	5 - 7	8 - 10	11 - 17	18 - 27
A. Total eggs laid	23	138	98	32
B. Eggs dying before swelling starts ..	0	27	22	12
C. Eggs dying after part or full swelling ..	3	8	6	3
*D. % dying because unfertilised	0.0	19.6	22.5	37.5
*E. % of fertilised eggs dying	13.1	7.2	7.9	15.0

(*The assumption is, see text, that eggs dying before swelling begins are unfertilised while eggs dying after swelling begins are fertilised.

$$D = \frac{B \times 100}{A} ; E = \frac{C \times 100}{A - B}$$

parent; that eggs laid by older females tend to be less viable. This was confirmed from the data of three jar experiments (numbers 1, 2 and 4). Further examination of jar experiment 1, moreover, makes it clear that any decrease in viability with age of parent comes from the non-swelling eggs, *i.e.* infertile eggs *sensu stricto* (line D, Table XIV). The eggs which die after swelling has begun show no such correlation (line E, Table XIV).

The Value of Laboratory Data.

The preceding laboratory observations were carried out with a view to their probable usefulness in interpreting events in the field. One must, however, keep in mind the essential artificiality of such data. As it happens (see later paper), the jam-jar environment is less artificial for the female than one might expect—at least for the first half of her life after primary emergence above ground, but for the male the conditions are exceedingly unnatural. In the subsequent papers of this series the emphasis is on field observations, of the population as well as the individual.

Summary.

The Garden Chafer, *Phyllopertha horticola* (L.) is the chief British representative of a type of world-wide pest. The following summary concerns the adult and its reproduction *under laboratory conditions*.

Adult feeding affects neither the number of eggs produced by the ovaries (productivity) nor the number laid (fecundity). Productivity depends entirely on the amount of fat-body stored away by the third-instar larva before hibernation.

The adult stage lasts about three weeks (3 to 35 days) in both males and females. Starvation shortens the life by a day or two. Females which lay no eggs (barren) are usually short-lived, *i.e.*, they die before oviposition is due to start, and comprise 14 per cent. of the population.

The fat-body is exhausted and the eggs are all matured by about the end of the first half of the adult stage. Oviposition and feeding apparently do not begin until the manufacture of eggs is completed. Individually, oviposition lasts five or six days (1 to 23 days), the more eggs laid, the longer does the oviposition period usually last. The female dies two or three days (0 to 10 days) later. Starved females have a rather shorter oviposition period. Unmated females may lay a few non-viable eggs just before they die.

The average female lays 13 eggs (0 to 46 eggs). More than 70 per cent. of females lay all or nearly all of the eggs manufactured from the fat-body. Apart from barren females, there is no significant difference in length of life between females that lay all of their eggs and those that lay only some.

Females are larger than males, being on the average 1.2 to 1.3 times heavier. Productivity and fecundity are positively correlated with female body weight (which is, of course, proportional to weight of fat-body). Thus regressions may be calculated such as:

$$F = 0.113W - 6.60$$

where F = number of eggs laid and W = weight of pupa in milligrammes. Female pupal weights vary from 80 to 310 mg. Body weight is not associated with the occurrence of barrenness. If all individuals always fulfilled themselves, a population would increase eight-fold annually.

There is not the slightest evidence of a fixed oviposition pattern. Four eggs may take nine days to lay while 27 may take only 24 hours. The same number of eggs may take a longer or shorter time to lay in larger or smaller dribblets, the numbers of eggs and the intervals between them being apparently quite random.

A female burrows down at a different point each time she has eggs to lay.

At each burrowing she deposits her eggs within a radius of one inch from the vertical line passing through her entrance hole on the soil surface. Eggs are laid singly in small cavities about quarter of an inch apart ($\frac{3}{16}$ to 1 in.).

Eggs hatch out in 4 to 6 weeks at temperatures of 15 to 17°C. Eggs failing to hatch vary between 4 and 28 per cent. of the total laid. They comprise both unfertilised eggs and, to a lesser extent, eggs which have been fertilised but die from other causes. The proportion of unfertilised eggs increases with the age of the female at oviposition.

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References.

- GRAY, R. A. H., PEET, W. V. & ROGERSON, J. P. (1947). Observations on the Chafer Grub problem in the Lake District.—Bull. ent. Res., **37**, pp. 455–468.
- RAW, F. (1951). The ecology of the Garden Chafer, *Phyllopertha horticola* (L.) with preliminary observations on control measures.—Bull. ent. Res., **42**, pp. 605–646.
- RITTERSHAUS, K. (1927). Studien zur Morphologie und Biologie von *Phyllopertha horticola* L. und *Anomala aenea* Geer (Coleopt.).—Z. Morph. Ökol. Tiere, **8**, pp. 271–408.
- THOMAS, I. & HEAL, G. M. (1944). Chafer damage to grassland in north Wales in 1942–1943 by *Phyllopertha horticola* L. and *Hoplia philanthus* Fuess. I. Notes on population, life history and morphology.—Ann. appl. Biol., **31**, pp. 124–131.
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BIOLOGY AND ECOLOGY OF THE GARDEN CHAFER,
PHYLLOPERTHA HORTICOLA (L.).

II.—THE CYCLE FROM EGG TO ADULT IN THE FIELD.

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Egg production of the Garden Chafer, *Phyllopertha horticola* (L.), in the laboratory was dealt with in Part I (Milne & Laughlin, 1956). The present paper describes in detail the cycle from egg to adult stage in the field (English Lake District). Only the sketchiest outlines of the cycle have been given by previous authors.

Location of Eggs.

The eggs are laid underground. Rittershaus (1927) remarks that the female is a strong digger, scooping the soil behind her with powerful strokes of her legs and disappearing into the ground in a very short time. Rittershaus also observes, nevertheless, that when the soil is baked hard by drought the female will readily utilise any chance opening, often the emergence holes of her own kind, to facilitate her entry. Gray, Peet & Rogerson (1947) likewise note the female having to make several attempts to penetrate the soil crust at the end of six weeks with practically no rainfall. In iron-hard drought conditions no doubt the female would utilise any crack or aperture she came across. Such conditions are rare, however, in the Lake District, and over the years from 1948 to 1952 at Buttermere, conditions never hindered a female from digging in at any point she chose.

Rittershaus (1927) says the depth at which eggs are laid is variable; the minimum is 2 inches but in deep soil they may be 8 inches down. Cameron (1941) put the egg depth at 2 to 4 inches, Gray, Peet & Rogerson (1947) at 1 to 4 inches according to depth of soil. Raw (1951) found 80 per cent. of eggs in the upper 3 inches of soil 3 to 4 inches deep.

Rittershaus (1927) states that "the eggs lie separately in tiny cavities", Cameron (1941) that they "are laid singly in the soil".

As mentioned above, no severe droughts occurred at Buttermere during oviposition periods in the years 1948 to 1952 and field observation showed that a female returning below ground always dug a fresh burrow. The orifices of burrows are fairly easily found on the barer parts of typical chafer-infested pasture land in the Lake District. Externally, of course, there is no way of telling whether an orifice has been an exit or an entrance, or indeed whether it was made by a Garden Chafer at all. However, early in the flight season, forty orifices, each isolated from others by at least 5 in. (questionable in one case, see below) and in some cases by several feet, were investigated by extracting a vertical $2\frac{1}{2}$ in. diam. core with the orifice as centre. These cores were then pared down carefully with a sharp knife. A diameter of $2\frac{1}{2}$ in. was expected to be sufficient since laboratory experiments with turves had already suggested that the Garden Chafer burrows more or less vertically when entering or leaving the soil and eggs are laid within a radius of one inch from the vertical through the orifice (see Milne & Laughlin, 1956).

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Twenty three of the forty cores contained nothing pertaining to the Garden Chafer (and in half a dozen cases the core site was further excavated to a diameter of 5 to 6 in. with the same result). The orifices in these cores could have been made by two other similar-sized and numerous species of beetle active at the same time as the Garden Chafer, or by other insects or earthworms.

The remaining seventeen orifices had been made by the Garden Chafer. Nine of the cores yielded only larval-pupal exuviae and therefore the orifices in these nine cases had been primary exit holes. Five yielded eggs only, respectively 2, 4, 5, 5 and 3 eggs. One had 2 eggs with a female beetle alongside, another, 4 eggs and a female. The remaining core produced 16 eggs and two females, one of the latter being at 1 to 1½ in. from the surface, the other at 2 to 2½ in. In this last case there may or may not have been another orifice nearby which was overlooked.

All four of the Garden Chafer females found were positioned vertically head downwards which reinforces the earlier suggestion (Milne & Laughlin, 1956), that this may be the normal posture for ovipositing. The field data also confirmed the previous laboratory finding that eggs are laid in separate cells, two or three times the width of the unswollen egg, and usually from ¼ to ⅜ in. apart (greatest distance being about 1 in.); and that the female, at any one visit underground, oviposits more or less directly below where she enters the soil, distributing her eggs within a volume best likened to a squat upright cylinder with a diameter varying from 1 to 2 in. and height ¼ to 1 in. Depth below surface could be measured accurately for 22 of the 41 eggs. In this smallish sample, the eggs were distributed between ¾ and 2½ in. below the surface of soil 3½ in. deep, with more than 70 per cent. of them between 1 and 1½ in. (see Table I).

TABLE I.

Depths at which eggs were laid below the soil surface in a sample of 22 eggs from nature.

Level (depth in inches) ..	< ¾	¾ - 1	1 - 1½	1½ - 1¾	1¾ - 1½	1½ - 2	2 - 2½	2½ - 2¾	> 2¾
No. of eggs ..	0	1	3	8	5	2	2	1	0

Incubation and Larval Instar Periods.

Observations have been made continuously over the five years beginning April 1948 in a population of *P. horticola* at Buttermere (English Lake District). Influenced by the weather, the start of the flight season (when eggs are laid) has varied between 21st May and 8th June, and the close between 15th June and 4th July. Naturally, incubation and stadium periods also vary in timing and duration. By soil sampling at strategic dates, the following approximations have emerged.

Incubation of the individual egg at Buttermere averages five weeks (4 to 6½ weeks). The first instar occupies individually about three weeks; the second instar about four weeks; and the third instar, up to hibernation, eight to ten weeks.

The mean dates (over 5 years) on which change to the various stages began in the Buttermere population are shown in Table II. On the average, first-instar larvae began to appear about the first week of July, second instars in the fourth week of July, third instars in the fourth week of August, and the earliest hibernators in the third week of October. As one would expect, it takes some

considerable time for all the individuals in the population to accomplish the change from one stage to the next. For example, in 1948 the change to third instar began about 25th August but 9 per cent. of the population were still second instars as late as 23rd September. There are never more than two successive stages in the soil, however, at the same time.

The population is usually hibernating by the middle of November, though a few stragglers may feed on to the middle of December.

TABLE II.

Mean annual dates (and ranges) when the population began to change to the various stages at Buttermere over five years.

Population change to	Range of date 1948 - 1952	Mean annual date
1st instar began	26 June - 10 July	3 July
2nd instar ,,	15 July - 1 Aug.	23 - 24 July
3rd instar ,,	17 Aug. - 26 Aug.	21 - 22 Aug.
Hibernation ,,	10 Oct. - 30 Oct.	20 Oct.

Ninety per cent. of individuals were hibernating by 30th Oct.-20th Nov., mean 9th-10th Nov.; all were hibernating by some date between 1st and 15th Dec.

Feeding Method and Food of the Larva.

A translation of part of Rittershaus's (1927) description of the mode of feeding is worth quoting: "The grub makes a small long-oval hole in the earth with smooth walls pressed tight but free of binding secretion. The size of the cavity varies with the size of the larva. . . . Typically the grub lies [on its side] in its cell with the legs encircling the anal segment. . . . Of movement below the surface, Leisewitz says, 'the mandibles open and close continually. . . .' My observations show that the grub breaks off chunks of earth and, by movements of the head and legs, pushes the chunks down into the 'U' of the body. As this space fills up the grub extends the middle part of the body and increases the space between the arms of the 'U'. When this is filled too, the grub turns [the legs aided by ventral hooked 'crawling pads'] . . . and pushes the blob of earth to the back of the cavity. If the earth is not all cleared, a second revolution is made. Then the grub turns a few more times, perhaps to press the walls tight. Thus the grub leaves no tunnel and all the earth through which it passes comes in contact with the mouthparts enabling any food to be perceived and eaten."

The severed tufts of grasses, lying around on infested pastures in late autumn, provide ample evidence that the Garden Chafer eats or at least cuts grass roots. Curiously enough there is no *published* record of grubs being maintained experimentally on grass roots alone. The present writer has reared Garden Chafers successfully from egg to adult in pure cultures (flowerpots) of *Festuca ovina* (sheep's fescue), *Agrostis tenuis* (fine bent) and *Lolium perenne* (perennial rye grass). All previous authors have stressed that the grub's food is *mainly* the roots of grasses. Since the grub eats grass roots and its natural habitat is pasture land, then grass roots could hardly be other than its main food material. After all, grasses always occupy most of the space on land worthy to be called pasture. But in fact, although it appears to avoid certain species, the grub also eats the roots, and can be reared experimentally on pure cultures of many plants, other

than grasses, found in pasture land. This will be gone into fully in a later paper on damage caused by the grub.

In field sampling, the writer once uncovered a third-instar larva clasping and apparently eating a weevil larva. The weevil lacked head and a small part of the thorax which was tattered as by chewing. Of course the weevil may have been dead when the chafer met it, but its remains looked quite healthy and fresh. On turning out an experimental pot of *agrostis-fescue* turf on one occasion the writer found a tattered newly-dead third-instar Garden Chafer; the only possible agency was its four fellows sharing the pot. Again there was no proof that the "victim" did not die naturally. But if the third-instar chafer is not a predator on other grubs including its own species, at least there is a possibility that it scavenges their remains when it chances to come across them.

The first and second larval instars are given over to growth, the third and final is occupied almost exclusively in storing food away in the form of fat-body. This store has to suffice for (a) maintenance through hibernation, (b) the third larval ecdysis, (c) pupation, (d) emergence, (e) the entire egg (or sperm) production and (f) part of the energy consumed in adult activity, because no food is taken from the onset of hibernation until the latter half of adult life (see Milne & Laughlin, 1956).

Feeding Level of the Larva.

"On hatching, the larvae remain for some time at about the same level as the eggs . . . grubs of the second instar are found feeding actively near the soil surface" (Gray, Peet & Rogerson, 1947). "Initially the vertical distribution of the larvae is the same as that of the eggs. After hatching, the larvae begin feeding and throughout the summer they are found in the root zone, often so near the surface of the soil that they can be found by scratching the surface." (Raw, 1951.)

In the *agrostis-fescue* turf at Buttermere, larvae feed at a higher and higher level as they grow. Here the first instars start feeding between $\frac{3}{4}$ and $2\frac{1}{2}$ in. from the surface, mean $1\frac{1}{2}$ in. The second instars are higher up and the third instars higher still. In early September, when there are more second than third instars, the larvae are found between $\frac{1}{2}$ and $1\frac{1}{2}$ in. from the surface, but by the beginning of October, when all are in the third instar, they are between $\frac{1}{4}$ and 1 in., mean $\frac{1}{2}$ in. The rise in the feeding level with age (growth) may be due to the need for more food per unit time and the increasing ability to cope with thicker roots (*i.e.*, of greater diameter). The nearer the surface, usually the thicker and more numerous the grass roots.

Rittershaus (and other authors) have claimed that drought and cold drive the feeding grubs deeper in the soil while wet and warm conditions reverse the process. Sooner or later in a prolonged drought a steep vertical gradient in soil moisture prevails and it is reasonable to suppose that, if conditions become too dry at normal levels, the grubs will follow the moisture down. In five years of close observation there has been no instance of this happening in the Lake District. However, a drought here is probably almost never so severe as in Germany. On the other hand, the writer is unwilling to believe that cold drives the feeding grub downwards to any significant extent. During severe November and December frosts in the Lake District, the grubs, if their stores are incomplete, remain at their normal feeding level even when a proportion are obviously being killed by freezing.

Hibernation.

At the beginning of the third stadium, the grub is a semitransparent greyish-white, with the dark gut contents showing clearly in the raster. By the time it

TABLE III.
Summary of data on depths of hibernation cells and of "pan" below the soil surface.

Place	Time	Cell depths			Soil (Pan) depths		
		Total sample units	Range (in.)	Mean (in.)	Total sample units	Range (in.)	Mean (in.)
Butternore	early April, 1951 ..	105	0.9 - 2.6	1.64 ± 0.03	—	—	—
"	early April, 1952 ..	64	1.2 - 3.4	1.98 ± 0.06	74	2.5 - 5.5	3.57 ± 0.16
"	late March, 1953 ..	52	0.9 - 3.3	1.92 ± 0.06	100	2.3 - 5.0	3.66 ± 0.05
Keswick	early April, 1952 ..	101	1.6 - 3.3	2.49 ± 0.04	48	3.0 - 6.0	4.60 ± 0.28
Rydal	early March, 1953 ..	112	0.8 - 3.8	2.00 ± 0.05	50	2.5 - 5.4	4.21 ± 0.08
"	early December, 1953 ..	101	0.8 - 2.9	2.00 ± 0.04	48	3.2 - 5.5	4.27 ± 0.09
"	mid-April, 1954 ..	98	1.0 - 3.2	2.17 ± 0.05	74	2.8 - 6.2	4.32 ± 0.06

is ready for hibernation 8 to 10 weeks later, the grub is an opaque rich creamy-white due to the large fat-body packing its interior. Feeding being now over and the gut evacuated, the grub descends from its final eating haunt close under the surface to make a roomy cylindrical hibernation cell with rounded ends which it occupies until its emergence as an adult. The cell walls are smoothly packed with fine soil granules.

Previous work on cell depth.

Rittershaus (1927) states that Garden Chafer grubs hibernated between 20 and 50 cm. (roughly 8 to 20 in.) below the soil surface in a field near Berlin in 1924.

Apparently generalising from observations over the period 1935 to 1940, Gray, Peet & Rogerson (1947) hold that in the Lake District the "fully fed grubs descend to the subsoil level for overwintering" and "the dormant larvae are found resting on the gravel bed"; also that "the majority of the pupae were found at sub-soil level practically resting on the gravel bed". The depth of the "pan" (gravel bed or rock) varied from 2 to $6\frac{1}{2}$ inches. No hibernating Garden Chafer was found by them above 2 inches and the deepest individual cell was $6\frac{1}{2}$ inches from the surface. The mean depth of larval cells "was about 4 inches".

Thomas & Heal (1944) and Raw (1951) give December data (*i.e.*, of hibernation) for Wales and Dorset, respectively, as follows:—

Depth in soil	Larvae (%)	
	Wales (1942)	Dorset (1944)
0-3 in.	93	22
Below 3 in.	7	78

The soil in Raw's case (see his Table VIII) was 4.5 to 9.0 inches, mean 6.2 inches, deep and in the other case (see their Table I) probably a little deeper—perhaps 8 inches.

Present observations.

The conflicting data from Wales and Dorset led to a more detailed examination of the question of cell depth in the Lake District. Study was confined to a fixed area of about two acres in each of three typical chafer-infested fields respectively at Buttermere, Keswick and Rydal.

In 1951, random 6 in. \times 6 in. blocks of turf were cut to pan depth but only cell depth was noted; this was measured vertically from the soil surface (*i.e.*, the point where vegetation mat and soil meet) to the centre of the cell. From 1952 to 1954, the distance from the cell centre to the pan immediately below it was measured in addition. Measurements were made in tenths of an inch. The combined data in full, *i.e.*, the position of each grub cell in relation to soil surface and pan in all the fields are shown in fig. 1. Statistical summaries of the 1951-54 data on cell depth by itself and pan depth by itself for each of the three fields are given in Table III. The frequency distributions of cell depths and pan depths in the samples from each field were all found to be approximately normal (slightly skewed).

Over all the data (633 cells), grubs on the average hibernated at a depth of about 2 inches, the extremes being 0.8 and 3.8 inches below the soil surface (Table III). Of 528 grubs for which pan depths were measured, 495 could have made their cells below 3 inches, the pan being at depths varying from 3.2 to 6.2 inches; yet only 19 or 4 per cent. of them chose to do so (fig. 1). The vast majority of grubs hibernated well above the pan even where the latter was 3 inches or less from the soil surface; only 8 in 528 or 1.5 per cent. could possibly be described as practically resting on the pan, *i.e.*, within half an inch of it. The

pan surface is a comparatively wet situation since drainage is slower below than above it. Grubs about to hibernate may keep off it for that very reason.

The possible importance of moisture conditions in deciding the hibernation level may be adduced from the Buttermere data (Table III). In the Buttermere field, mean cell depth was 1.64 inches for the winter of 1950/51, 1.98 for 1951/52 and 1.92 for 1952/53, results in the last two years being practically identical. The mean difference between the first and the two subsequent winters, 0.31 inch, is significant ($P = < .001$) and the 5% fiducial limits are 0.28 and 0.40 inch. Thus cells were about one third of an inch deeper on the average in both 1951/52 and 1952/53 than in 1950/51. This may have been due to weather about the time mass hibernation occurred. The bulk of hibernation takes place in October. The most likely factors influencing hibernation level are ground temperatures in October and rainfall in September–October. Data from the official meteorological station at Keswick, 6 miles from Buttermere, are set out

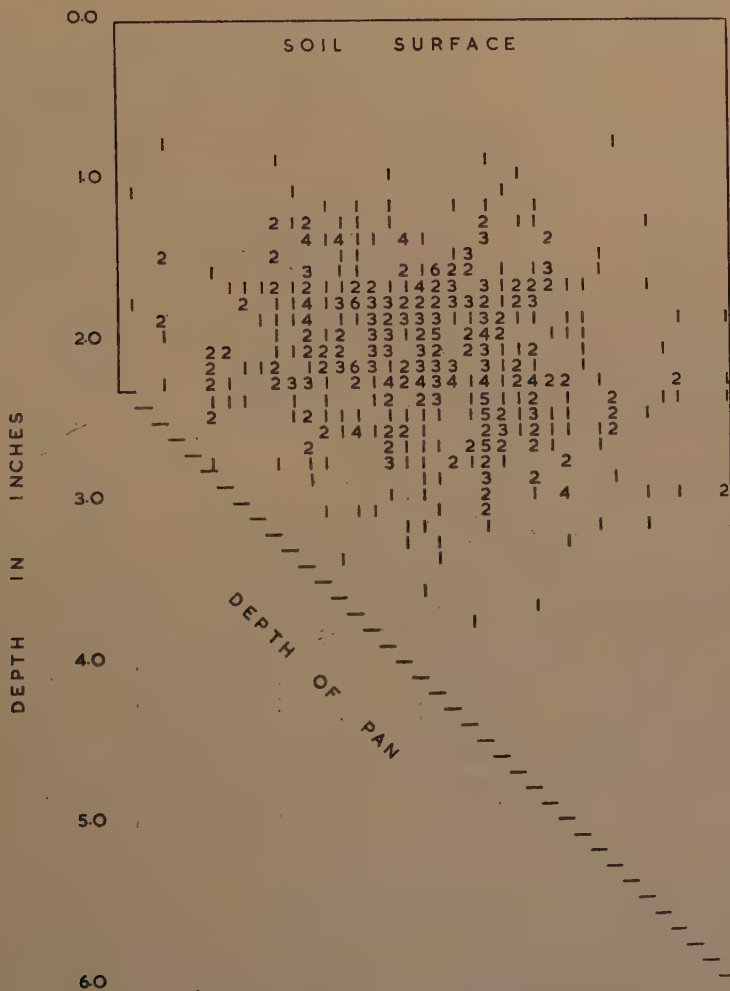


Fig. 1.—Distribution of Garden Chafer hibernation cells in relation to soil surface and pan.

in Table IV. Conceivably a greater degree of cold in October might drive grubs to hibernate at a deeper level. The averages in Table IV give no indication that ground temperature could have been the cause in the present case but the rainfall figures are suggestive. The amount of rainfall immediately preceding as

TABLE IV.

Ground temperature for October and rainfall for September & October at Keswick, 1950-52.

	1950	1951	1952
Mean ground temperature* for October (°F.)	46.5 (8.1°C.)	48.5 (9.2°C.)	44.7 (7.1°C.)
Days with ground frost in October	6	1	10
Total rainfall for September and October (mm.)	513 (20.25 in.)	252 (9.9 in.)	297 (11.1 in.)
Rainfall as % of normal for September and October ..	204	100	118

* This is the average of the sum of mean air temperature and mean temperature at 1 foot depth in the soil.

well as during the mass descent into hibernation will determine the level at which a given set of moisture conditions is to be met. If grubs going into hibernation have a moisture preference less than the maximum possible then they will make their cells nearer the soil surface in a wetter-than-normal September-October. This period had little more than the normal amount of rain

TABLE V.

Mean cell depth in different depths of soil in the fields studied at Buttermere and Keswick in 1952.

Soil (pan) depth (in.)	Numbers of cells		Mean cell depth (in.)	
	Buttermere	Keswick	Buttermere	Keswick
2.5 - 2.9	13	0	2.05	—
3.0 - 3.4	45	5	1.90	2.36
3.5 - 3.9	39	8	1.93	2.57
4.0 - 4.4	15	11	1.97	2.51
4.5 - 4.9	1	40	—	2.43
5.0 - 5.4	2	25	—	2.60
5.5 - 5.9	1	7	—	2.40
6.0 - 6.4	0	5	—	2.52

in 1951 and 1952 but twice the normal fall in 1950. Hence the cells being on the average one third of an inch nearer the surface in 1950/51 may have been the outcome of an extremely wet September–October 1950.

There would appear to be some evidence in Table III that grubs may hibernate lower down in a field with deeper soil (*i.e.*, deeper pan level). Thus in the Keswick field, which has soil about one inch deeper (5% fiducial limits of difference being 0.94 & 1.12 in.) than the Buttermere field, the hibernation cells were situated about half an inch more (5% limits 0.44 & 0.58) below the surface on the average in 1952. But while there is this difference *between* the two fields, Table V shows no like relation between cell and soil depths *within* each field: average cell depth within each field is practically the same for all soil depths greater than $2\frac{1}{2}$ or 3 inches. Clearly, then, cell depth is not necessarily influenced by soil depth as such. The governing factor may be the moisture conditions. The Keswick soil contains a much larger proportion of gravel and therefore drains more freely so that any particular set of moisture conditions occurs at a lower level than in the Buttermere soil.

Conclusions.

The approximate average results of the various authors (so far as can be estimated from their data) may be tabulated thus:—

Author	Soil depth (in.)	Cell depth (in.)
Present writer	4	2
Gray, Peet & Rogerson (1947)	4+	4
Raw (1951)	6	ca. 4+
Thomas & Heal (1944)	ca. 8	ca. 2
Rittershaus (1927)	> 14	ca. 14

Obviously the grub does not necessarily hibernate at a deeper level in fields with deeper soil. The previous authors give no pertinent information on moisture conditions of their soils. One cannot, therefore, test the suggestion arising from the present work (see above) that moisture conditions may decide the level at which hibernation occurs. In any case there is a serious drawback to that suggestion. It is true that the amount of water at any particular level below the surface varies with soil character (as influencing drainage) and rainfall. But the difficulty is to imagine how a grub can possibly gauge the *general* moisture conditions anywhere in the soil. At all levels in a soil the moisture content usually fluctuates continually and irregularly somewhere between (and at times including) the extremes of complete saturation and absence of “free” water. The deeper in the soil, of course, the greater will be the average water content over a period. But the Garden Chafer can neither forecast the weather nor calculate an average. It could only be influenced by the moisture conditions prevailing at the time it makes its hibernation cell, and this, with rainfall varying as it does, would be a most unreliable criterion (a sample of one unit!) for average moisture conditions over the 6 or 7 months to follow. Clearly, one cannot, at present, decide what governs the level at which hibernation takes place.

Prepupa and Pupa.

The external characteristics of prepupation are seen in late March and in April in the field. Over the five years 1948 to 1952, the first signs in the population at Buttermere have been noted as early as 24th March and as late as 7th April. The average individual spends between 3 and 4 weeks in prepupation.

Before the prepupal stage, the larva, if touched with a blunt needle, always reacts by contracting ventrally so that head and raster come closer together,

with curved dorsum outwards. After the prepupal stage has begun, stimulation produces the opposite effect: head and raster go apart until the body is extended full length with the ventral surface slightly arched outwards. Nearer pupation, stimulation evokes no response, the power of movement being lost first in the legs. In the field the prepupa, before it becomes helpless, fixes its tarsi in the wall of the hibernation cell. The creature then contracts ventrally until the spiny raster, now empty and flat and slightly curved at the tip, "hooks" into the wall a little behind the legs. Thus "anchored" fore and aft, the pupa later splits the third-instar skin dorsally from end to end. Until emergence, the pupa lies passive within the split larval skin inside the hibernation cell.

Dates for the onset of pupation and for the commencement of the flight season (appearance of the first beetles above ground) in the same Buttermere population are given in Table VI. The intervals between these two happenings

TABLE VI.

Dates on which pupation started and became complete, and dates on which the flight season started, in a population at Buttermere over five years.

Year	Pupation		Flight season started
	Started	100 per cent.	
1948	April 18	April 27	May 24
1949	April 21	April 29	May 21
1950	April 21	May 12	June 2
1951	May 3	May 17	June 8
1952	April 18	April 28	May 22

were respectively 36, 30, 42, 36 and 34 days over the five consecutive years 1948 to 1952. But as will be shown later the adult takes some time to appear above ground after emergence from the pupal skin. In fact, the individual pupal period in the field varies between 3 and 5 weeks and is usually about one month.

Sex Ratio in Pupal Populations.

Rittershaus (1927) shows how to sex pupae, and holds that "larval cultures show a 50/50 sex ratio". The total populations of a number of random square yards were sexed each year in Upper High House Field at Buttermere from 1948 to 1952. Population per sq. yd. varied from 7 to 127, mean 54.5. The sex ratios were as follows:—

Year	No. of sq.-yd. samples	Male/Female
1948	4	1.25
1949	8	1.19
1950	17	1.89
1951	14	1.26
1952	14	1.13

Clearly there are always rather more males than females in a field population, sometimes considerably more as in 1950. The relation of sex ratio to population density will be taken up later.

The Timing of Male and Female Development in a Population.

The supply of adults for laboratory experiments comes from field collections of grubs or pupae which are kept in tubes of soil or in the "cells" of specially made blocks of plaster of paris. Routine examination of the cultures in 1948 suggested that adult emergence from the pupal skin is somewhat earlier among males than among females. This was confirmed in 1949, the average male emerging 2 to 4 days before the average female (mean range from several experiments). These data, however, were lacking in detail, and temperature conditions were unnatural, being more or less lower than in the soil and having little or no fluctuation. While there was no doubt that females emerged later than males in the foregoing experiments, one wanted to know how much later it was under natural temperature conditions.

In 1950, random samples of 100 male and 100 female pupae, collected over Upper High House Field, Buttermere, were kept in damp plaster blocks inside a biscuit tin. It was found that if the biscuit tin stood in a wooden cupboard of the double-walled wooden hut (serving as a field laboratory at Buttermere) then temperature conditions for culture pupae were very similar to those obtaining for pupae in the soil outside. Data for one week suffice to illustrate this, *viz.*:—

	Max. range	Daily temperature (°C.)		
		Max. mean	Min. range	Min. mean
In culture (plaster block)	17.2-23.3	19.9	6.7-12.8	10.1
In nature (soil 1½-2 in. deep)	16.7-21.1	18.2	10.0-13.3	11.6

The daily total emergences of males and females are shown as population histograms in fig. 2,a,b. These histograms have, as one would expect, approximately the form of the normal curve. The first male (31st May) emerged two days earlier than the first female. Four days later (4th June), 82 per cent. of males had emerged but only 58 per cent. of females. The mean emergence was 4.4 days after 30th May for males and 5.3 days for females, a difference of about one day. The female population emergence lagged about a day behind the male

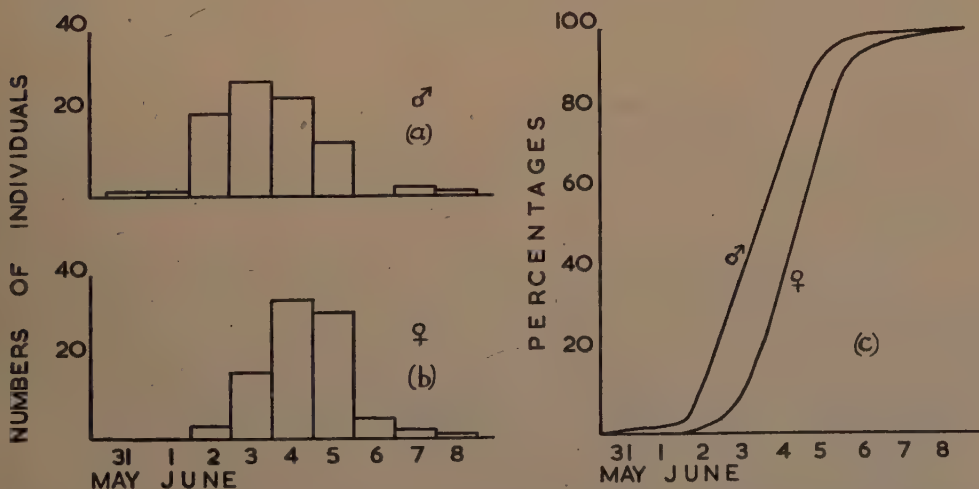


Fig. 2.—(a) Numbers of adult males and (b) of adult females emerging daily from random samples of 100 male and 100 female pupae collected in the study field at Buttermere. Ninety males and 92 females emerged as adults; the others died as pupae. (c) The same shown as cumulants, *i.e.*, the accumulated numbers of males and of females emerged since the start (31st May), expressed as percentages of the total emergence.

until nearly 80 per cent. emergence had been attained by both (fig. 2,c). A smaller repeat of this experiment confirmed the findings; females began emergence a day behind males and the difference between their means of emergence was again one day.

The male precedence in development is not confined to emergence from the pupal skin. The male population curve, though always overlapping considerably, is nevertheless appreciably earlier than the female curve at all stages from pupation to entry into activity above ground. This is amply evident to the observer constantly in the field.

Adult Pigmentation.

Before the pupal skin bursts open, the adult is almost fully pigmented; only the elytra and part of the abdomen still remain more or less white or pale. The adult remains practically motionless inside the cast larval skin (with the pupal exuvium pushed to the rear) for a few hours or even days after pigmentation is complete. Daily observation of 16 males and 15 females among individuals of the experiment for fig. 2 showed pigmentation to be complete in the following intervals measured from the bursting of the pupal skin:—

	Within 24 hr.	Between 24 & 48 hr.	More than 48 hr.
Males	13	3	0
Females	13	2	0

Thus the great majority attain full pigmentation in under 24 hours. The minimum time could not be ascertained from a once-daily observation but one male at least is known to have become fully coloured in less than 18 hours. There appears to be little or no difference in the rate of coloration for males and females. It follows therefore that the female population coloration curve will still have the same lag behind the male as in the case of bursting the pupal skin.

The elytra of the Garden Chafer are of a light bronze colour. Occasionally, however, one finds male and female "sports" with black elytra. These "sports" are seen at the rate of 3 or 4 per season during the course of looking at many thousands of individual beetles in the field.

The Ascent from the Hibernation Cell.

Complete observation of the adult ascent in the field from the hibernation cell into activity above ground is obviously a very difficult task. Attempts were therefore made to study the details in glass tubes of soil simulating natural conditions.

A pupa, still lying in its larval exuvium, was placed at the bottom of a $3 \times \frac{3}{4}$ in. tube filled to a depth of 2 in. with soil (through a 2 mm. sieve) topped with a $\frac{3}{16}$ -in. layer of sawdust. The tube had a perforated cork leaving about $\frac{3}{4}$ in. air space above the soil. A random sample of 23 male and 23 female pupae from a field population was set up in 46 tubes. A 47th tube, made up in the same way, contained a thermometer, instead of a pupa, with the bulb occupying the pupal position. The tubes were all sunk to the level of the sawdust surface in a light-proof wooden box covered with rubber sheeting having 47 circular apertures such that the rubber fitted tightly round each tube, so excluding light. Thus, each individual was in darkness until it reached the sawdust layer and above that came into open-sky light, but *not* direct sunlight, close to a north-facing window in the field laboratory.

Without jarring at all, a tube could be pulled out for a moment in order to note when the adult emerged and its progress towards the surface. This was

done daily at 10 a.m. and 6 p.m. Once at the undersurface of the sawdust layer, a beetle could be seen without disturbing the tube and observations were then made at 30-minute intervals from 9 a.m. to 6 p.m.

Eight males and nine females died before breaking through the sawdust. One male and one female were discarded after using them in a minor test of the effect of sunlight (see below). The findings from the remaining 14 males and 13 females confirmed a similar experiment a year earlier and were as follows (see Table VII).

Behaviour in the male and female groups was practically identical in every respect, therefore the data may be lumped together and "beetle" refers equally to either sex.

TABLE VII.

Data of experiment designed to show details of the beetle's ascent from the winter hibernation cell into the activity of the flight season above ground.

	Days after emergence before beginning to climb upwards	Days taken for ascent (2 in.) to undersurface of sawdust	Days spent under the sawdust and/or in the sawdust layer	Total days between emerging from the pupal skin and emerging into activity*
Males				
1	3.0	2.5	2.5	8.0
2	3.0	1.0	3.5	7.5
3	4.0	2.0	2.5	8.5
4	2.5	1.5	4.0	8.0
5	3.0	2.0	3.0	8.0
6	2.5	2.0	3.5	8.0
7	4.5	1.0	1.5	7.0
8	4.5	2.0	1.0	7.5
9	1.0	0.5	6.0	7.5
10	5.0	1.5	1.5	8.0
11	3.5	0.25	2.25	6.0
12	2.5	4.0	1.5	8.0
13	6.5	0.25	1.25	8.0
14	5.5	1.5	1.5	8.5
Means	3.64	1.57	2.54	7.75
Females				
1	5.0	1.0	0.5	6.5
2	5.0	1.5	0.5	7.0
3	5.0	1.5	1.0	7.5
4	1.5	2.0	4.0	7.5
5	4.5	2.0	2.0	8.5
6	1.5	2.5	4.0	8.0
7	3.0	3.0	1.5	7.5
8	3.0	0.5	4.0	7.5
9	2.5	3.0	2.0	7.5
10	4.5	1.5	1.5	7.5
11	7.0	0.5	0.5	8.0
12	3.0	2.0	2.5	7.5
13	3.0	2.0	2.5	7.5
Means	3.73	1.77	2.00	7.54

Time counted from mid-point between observation intervals.

* A beetle was considered to have "emerged into activity" on the first day it stayed on the surface of the sawdust for the whole or major part of the period between 10 a.m. and 4 p.m.--see text.

After emerging, the beetle remained where it was for 1 to 7 days (mean 3·7 days) while pigmentation was being completed and the cuticle hardening. Then began the ascent.

If the beetle had ascended at all between two observation times, the distance was 0·25 to 1·00 in., mean 0·45 in. over eight hours, and double that over sixteen hours. Data for the eight-hour intervals will suffice to illustrate, *viz*:—

Ascent in inches	Number of beetle-ascents
0·25	17
0·50	12
0·75	5
1·00	3
>1·00	0

The beetle burrowed up a little way, then rested, usually repeating this alternation again and again until it reached the undersurface of the sawdust. Despite the inadequacy of the observation intervals (10 a.m. and 6 p.m. each day) at this stage, evidence emerged that one or two of those numerous rests was rather prolonged. In 15 of the 27 beetles, rests of 8, 16 or 24 hr. were recorded in 9, 6 and 2 instances respectively—one male and one female each having two such rests (the male at 0·50 and 0·75 in. and the female at 0·25 and 0·75 in. from the tube bottom), the remaining 13 beetles recording only one rest each. The distribution of these prolonged rests according to height above the tube bottom, *i.e.*, above the “cell,” was as follows (to nearest 0·25 in.):—

Height above “cell”	Number of prolonged rests
0·25	2
0·50	8
0·75	3
1·00	2
1·25	2
>1·25	0

Bearing in mind that only a fraction of rests >8 hr. would be recorded, this distribution suggests that the beetle generally needed 8 to 24 hr. rest after accomplishing about one third of its journey to the surface.

Once started upwards, the beetle required 0·25 to 4·00 days (mean 1·7 days) to ascend the 2 in. of soil between its “cell” and the sawdust layer. From then on, observation was stepped up to 30 min. intervals between 9 a.m. and 6 p.m.

Conditions at the undersurface of the sawdust were meant to represent conditions at the underside of the basal layer of the typical Garden Chafer sward (fine, close-cropped *agrostis/fescue*) in the field outside the laboratory. Whereas the soil was in darkness, the undersurface of the sawdust was weakly illumined by the sky light filtering through the thin layer of orange-white wood particles. On reaching this undersurface, 23 of the beetles halted without breaking through the sawdust layer, and nine of these were actually seen arriving between 9 a.m. and 6 p.m. In the remaining four cases, each beetle had still some ascent to make at 6 p.m. but at the first observation on the following morning the sawdust was found churned up with soil particles, indicating a break-through between 6 p.m. and 9 a.m.; the beetle, however, was not out on the upper surface but buried close beneath it. In an *additional* two of the latter cases (the discarded beetles mentioned before) the distal halves of the elytra were just showing, but when subjected to bright sunlight at the laboratory door, these beetles immediately descended until completely covered by the mixture of soil and sawdust. All this suggested that the halt just below the upper surface was a negative reaction to light. The halt amounted to 0·5 to 6·0 days (mean 2·3 days). The beetle

would them come out on the surface somewhere between 9 a.m. and 2 p.m. and stay there for an hour or two, or more usually up to 4 or 5 p.m. This obviously was the primary emergence into activity above ground.

Each one of the 27 beetles thus showed three distinct stages in the period between pupal ecdysis and purposeful emergence above the sawdust: (1) the hardening stage, 3.7 days; (2) the ascent, 1.7 days; and (3) the halt just below the surface, 2.3 days. Individuals showed rather wide variation in the time taken for any one stage, *viz.*, stage (1), 1.0 to 7.0 days; stage (2), 0.25 to 4.00 days; stage (3), 0.5 to 6.0 days; but they showed very little variation in the time taken to cover all these stages, *viz.*, 6.0 to 8.5 days or an average of 7.7 days.

Since there were several artificialities in the experiment (*e.g.*, relatively loose soil, confinement to a vertical column of $\frac{3}{4}$ in. diameter, sawdust for vegetation mat), the question naturally arose as to whether the above results were a reliable guide to what the beetle actually does in nature. Information, accumulated during field collecting and observation, suggested that they were, and this was confirmed as follows. It was shown (Table VIII) that temperature conditions at

TABLE VIII.

Differences between maximum and between minimum temperatures at 2-in. depth of soil in experimental tubes (A, see text and Table VII) and in the field (B).

Differences ($^{\circ}$ C.) for A—B.

Day	Maximum	Minimum
5 June ..	-1.3	-0.5
6 „ ..	+6.6	-1.6
7 „ ..	+0.6	-0.5
8 „ ..	0.0	-3.3
9 „ ..	+2.2	-2.2
10 „ ..	+1.7	-0.6
11 „ ..	+2.2	-0.6
12 „ ..	+2.8	+2.2
13 „ ..	+0.6	0.0
14 „ ..	+2.3	+2.2
15 „ ..	+4.5	+1.1
16 „ ..	+3.3	-0.5
Means ..	+2.1	-0.3

the bottom of the experimental tubes were very similar to temperature conditions at a depth of 2 in. in the field. It follows therefore that emergence from the pupal skin would occur at approximately the same time in the tubes and in the field. If, then, the curve of primary emergence above the sawdust coincided in time with that upon the grass sward in the field, it would be reasonable to

conclude that our experimental beetles were behaving quite naturally in the tubes. In the experimental tubes the first beetle emerged into activity (*i.e.*, stayed above the sawdust for the first time) on 8th June, and the majority did so between 12th and 17th June. In the field from which the experimental sample came, the first adults appeared on the sward surface on 8th June, and the bulk of the population between 12th and 19th June. Clearly the experimental picture is trustworthy.

About seven or eight days elapse therefore between the individual's emergence as an adult and its primary emergence into activity above ground. The suggestion by Gray, Peet & Rogerson (1947) that the whole process cannot take "more than a few hours at most" is not borne out. Where the period exceeds seven or eight days this is due to an extension of the halt at the base of the sward. Inclement weather can extend this halt several days beyond the normal two or three.

The Primary Emergence of the Sexes into Activity on the Grass Sward.

The experimental procedure of the preceding section was repeated with the total undamaged pupae, 73 males and 40 females, from two separate square yards of turf in Upper High House Field at Buttermere. The aim was to get some idea of the time-relation between the population curves of male and female primary emergence into activity on the sward (here represented by the sawdust layer).

TABLE IX.

Male and female population curves of primary emergence above the sawdust layer in experimental tubes.

	June						
	5	6	7	8	9	10	11
No. of males	1	6	13	8	1	1	0
No. of females	0	1	3	8	3	0	2

(This is equivalent to primary emergence into activity upon the grass sward—see text.)

Thirty males and seventeen females survived the experiment. Their primary emergences above the sawdust are tabulated in Table IX. It will be seen that the female section of the population becomes active about a day later than the male all through. This is the same as in the case of emergence from the pupal skin. Other experiments and observations, both in the field, confirmed that females are later than males in making their primary emergence into activity, the full data on which will be given in a later paper.

The Overlaps of Development Stages in the Population.

In Britain, the eggs of the Garden Chafer are always laid some time between the third week of May and the first week of July inclusive. Individual development from egg to reproducing adult takes 12 months, or at least never *significantly* more or less than 12 months. The consequence is that only one generation is present in the soil at any time outside the population oviposition

period. During the latter period there are, of course, two generations present, namely, adults and their eggs; but the adults are all dead by the time the first eggs hatch out.

As pointed out earlier, it naturally takes some time for all the individuals in a population to accomplish the change from any one development stage to the next. The interval between the first and last individual change may be called the overlap. During this overlap, two stages exist side by side in the soil (*e.g.*, 1st and 2nd instars, or feeding and hibernating 3rd instars, or pupae and adults, to name at random three of the overlaps); and the proportion of the maturer of the two stages of course increases progressively from < 1 per cent. to > 99 per cent. within the overlap. Between overlaps only one stage is present. The mean overlap in days at each of the eight steps in development which take place in the soil is shown in Table X.

TABLE X.

The overlaps of developmental stages in the population.

Overlap of	Occurs in	Duration of overlap in days Mean (range 1948-1952)
Adults and eggs	May-June	32 (22 - 38)
Eggs and 1st instars	June-July	22 (17 - 28)
1st and 2nd instars	July-August	19 (16 - 21)
2nd and 3rd instars	August-September	24 (14 - 29)
Feeding and hibernating 3rd instars ..	October-November	41 (30 - 61)*
Hibernating 3rd instars and prepupae	March-April	(12+) ? **
Prepupae and pupae	April-May	12 (8 - 21)
Pupae and adults	May-June	8 (6 - 10)

* In some years a tiny minority of grubs continue feeding into the first half of December. If these are included the overlap period becomes 49 (35-65) days.

** Data here were rather scanty but the impression was that this overlap would be only a little more than 12 days.

The striking thing about the overlap is that its duration (in days) fluctuates very considerably throughout the development cycle, *viz.*, 32 \rightarrow 22 \rightarrow 19 \rightarrow 24 \rightarrow 41 \rightarrow 12+ \rightarrow 12 \rightarrow 8 (see Table X). Soil temperatures are rising in the Lake District until August then falling until February. The sequence [32 \rightarrow 22 \rightarrow 19] falls within a period of rising temperature, [\rightarrow 24 \rightarrow 41 \rightarrow] within a period of falling temperature, and [12+ \rightarrow 12 \rightarrow 8] within a period of rising temperature. It seems obvious that temperature is actually the cause of the shortening or lengthening of the overlaps in these sequences: a rising temperature within any stage of population development will cause individuals entering the stage later to develop more rapidly than those entering earlier; and conversely a falling temperature will cause later individuals to develop more slowly; and so the overlap is shortened or lengthened accordingly. On the other hand, the spectacular reduction of the overlap from 41 days on entering to little more than 12 days on coming out of hibernation (*i.e.*, 41 \rightarrow 12+) cannot be ascribed to temperature in the same way as above. In fact, soil temperature is falling throughout

hibernation except for a slight rise over a very short time at the end. A different reason must be sought. The hibernation period, a true diapause, is long, occupying 4 to 6 months or from one third to one half of the individual life span. During this lengthy interval, individuals going into hibernation earlier no doubt complete their diapause development (see Andrewartha, 1952) at a correspondingly early date but they have to "mark time" thereafter until the arrival of threshold spring temperatures. Meanwhile later individuals are catching up until the maximum difference in developmental age is reduced from 41 to 12+ days.

Overlaps, as defined, are actually measures of the range of developmental age among individuals. It has been noted above that this range fluctuates widely at intervals in the growth of a generation. But it contracts to the minimum (8 days) as the population approaches maturity. This facilitates mating as will be shown in the next paper.

Summary.

The Garden Chafer, *Phyllopertha horticola* (L.), has three larval instars, the third ending in hibernation, which gives way to a prepupal stage. The development cycle occupies 12 months and only one generation is present in the soil at any time. From a study extending over five years, 1948 to 1952, the cycle from egg to adult in the English Lake District may be outlined as follows:—

At the earliest, oviposition starts in the latter half of May. In soil $3\frac{1}{2}$ in. deep, eggs are laid at an average depth of $1\frac{1}{2}$ in. (range $\frac{3}{4}$ to $2\frac{1}{2}$ in.). Other authors report that where the soil is sufficiently deep, the maximum egg depth may extend to four inches in the Lake District and even eight inches elsewhere. The eggs are spaced about a quarter of an inch apart (max. 1 in.), each in a tiny earthen cavity, all more or less directly below the point where the female enters the soil. Incubation of the individual egg averages five weeks.

The first instar occupies individually about three weeks on the average; the second instar about four weeks; and the third instar, up to the beginning of hibernation, eight to ten weeks. On the average also, first-instar larvae begin to appear in a population about the first week of July, second instars about the fourth week of July, third instars about the fourth week of August, and the earliest hibernators about the third week of October. Except for a few stragglers occasionally in early December, the entire population is generally hibernating by the end of November. The hibernation is a true diapause.

A detailed description of the method of feeding is given. The larva consumes plant roots which it obtains by tunnelling through the soil. Since its natural habitat is pasture land, grass roots are the main food. It probably also eats invertebrate carrion occurring by chance in its path. The first and second larval instars are given over to growth, the third and final is occupied mainly in storing up fat-body. This store has to suffice for maintenance during the remainder of development and also for the entire egg or sperm production.

On hatching, the larvae feed at about $1\frac{1}{2}$ inches ($\frac{3}{4}$ to $2\frac{1}{2}$ in.) depth in the soil, i.e., at egg-level. As they grow, however, they ascend until latterly, as third instars, they are feeding about $\frac{1}{2}$ inch ($\frac{1}{4}$ to 1 in.) from the surface. This progressive rise is probably dictated by the increasing need for a more copious food supply. With the possible exception of a very prolonged drought, weather has no effect on the level at which larvae feed.

Larvae hibernate at 2 inches (0.8 to 3.8 in.) below the surface of soil 4 inches (2.3 to 6.0 in.) deep, i.e., well above the "pan" (gravel bed, or rock). In other localities other authors have recorded hibernation at the same as well as greater depth in deeper soils. The existing data are insufficient to show what governs the choice of depth in the soil.

On the average, prepupation begins in a population about the end of March and, individually, lasts between three and four weeks; pupation begins in the third week of April and lasts about four weeks. The pupa lies inside the last larval exuvium in the hibernation cell. Sex can easily be discerned in the pupa. There are always rather more males than females in a field population, considerably more in some years. Pupal sex ratios ranged from 1.13 to 1.89. On the average, male pupation precedes female by one day or a little more.

Behaviour after the splitting of the pupal skin is the same in male and female. At first, for about four days (1 to 7), the adult remains motionless in the hibernation cell. Then, alternately burrowing and resting, it ascends to the base of the sward in about two days ($\frac{1}{4}$ to 4). At the sward base it now halts for about two days ($\frac{1}{2}$ to 6) before emerging into activity upon the sward surface for the first time; this halt of two days may be prolonged by one or more days if weather is unsuitable when a beetle is ready to become active. *In toto*, given no weather hindrance, the individual transit from cell to sward surface usually occupies rather more than one week (7.7 days, range 6.0 to 8.5). On the average, the first active beetles are seen in the last week of May but may be as early as the third week of May or as late as the second week of June, according to the weather. The male precedence over females in development is maintained from pupation onwards, hence the first males are always active upon the sward at least one day before the first females.

It takes some considerable time for all the individuals in a population to accomplish the change from any one particular stage of development to the next. There are, however, never more than two successive stages in the soil at the same time. The period of overlap of two stages in the population fluctuates widely (8 to 41 days) from step to step in the development cycle. This is the result of the seasonal rise and fall in the soil temperature, and of diapause. The overlap, which is really a measure of range of developmental age among individuals, contracts to the minimum (8 days) as the population approaches maturity. This facilitates mating.

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References.

- ANDREWARTHA, H. G. (1952). Diapause in relation to the ecology of insects.—*Biol. Rev.*, **27**, pp. 50–107.
- CAMERON, A. E. (1941). Insect and other pests of 1940.—*Trans. Highl. agric. Soc. Scot.*, (5) **53**, pp. 77–97.
- GRAY, R. A. H., PEET, W. V. & ROGERSON, J. P. (1947). Observations on the Chafer Grub problem in the Lake District.—*Bull. ent. Res.*, **37**, pp. 455–468.
- MILNE, A. & LAUGHLIN, R. (1956). Biology and ecology of the Garden Chafer, *Phyllopertha horticola* (L.). I. The adult and egg production.—*Bull. ent. Res.*, **47**, pp. 7–22.
- RAW, F. (1951). The ecology of the Garden Chafer, *Phyllopertha horticola* (L.) with preliminary observations on control measures.—*Bull. ent. Res.*, **42**, pp. 605–646.

- RITTERSHAUS, K. (1927). Studien zur Morphologie und Biologie von *Phyllopertha horticola* L. und *Anomala aenea* Geer (Coleopt.).—Z. Morph. Ökol. Tiere, **8**, pp. 271–408.
- THOMAS, I. & HEAL, G. M. (1944). Chafer damage to grassland in north Wales in 1942–1943 by *Phyllopertha horticola* L. and *Hoplia philanthus* Fuess. I. Notes on population, life history and morphology.—Ann. appl. Biol., **31**, pp. 124–131.
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HOST SPECIFICITY OF *RHIPICEPHALUS SANGUINEUS* (LATREILLE) AND *R. SECUNDUS* FELDMAN-MUHSAM IN ISRAEL.

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Various authors studying the epidemiology and host relationship of *Rhipicephalus sanguineus* (Latr.), *sens. lat.*, state that this tick attacks a wide range of hosts including dogs, sheep, cattle, horses, etc. According to Hoogstraal (1954), "*R. sanguineus* is extremely common on dogs and other domestic animals everywhere in the Near East". With respect to Greece, Pantazis (1947) mentions a very large range of hosts, *i.e.*, dogs, cats, foxes, horses, sheep, goats, cattle, camels, etc. In Algeria, Sergeant & others (1945) do not specify the hosts but say that *R. sanguineus* appears in April in large numbers on farm animals. Colas-Belcour & Rageau (1951) state that in Tunisia *R. sanguineus* is to be found on dogs, cattle, goats, sheep, etc. According to Theiler (1948), *R. sanguineus* is found in Portuguese East Africa especially on dogs and occasionally on cattle and other domestic stock.

Since 1952, when it became evident that *R. sanguineus* (Latr.), 1806 is not one species but two distinct ones, *i.e.*, *R. sanguineus, sens. str.*, and *R. secundus* Feldman-Muhsam, 1952, it was thought advisable to examine large batches of ticks from different hosts in order to study any host specificity which might be found in these two closely related species. As it is possible to distinguish between the two species only by the mounted genital aperture of the female or by the larvae or nymphs, the following data will refer mainly to females. Ticks examined were from a collection of the Department of Agriculture of the Government of Palestine and from our own collection. As regards the material from the former collection, records included the date, place and host, but not the number of host animals examined. The material originates from practically all parts of Israel and the territory of the Palestine Mandate, now outside Israel, in all seasons of the years 1928-1931 and 1950-1951, and from various suspected carriers. Specimens collected at a certain place and time were considered as a batch even if taken from more than one animal of the same species.

As on every farm there is generally only one dog, but many head of cattle, sheep and goats, a batch from a dog will often include specimens from a single animal, but batches from domestic stock, specimens from many hosts.

It is evident from Table I that there is a very clear, but not absolute, host specificity of the two species. *R. sanguineus, sens. str.*, is more prevalent on dogs, and *R. secundus* on sheep, goats and cattle. This conclusion is based on the examination of more than 150 specimens from each host and the differences between respective percentages are striking. Incidentally, *R. secundus* also parasitises dogs, and *R. sanguineus, sens. str.*, cattle, sheep and goats. It may be suggested that this situation exists in other Mediterranean countries too, because in material from neighbouring countries (Turkey, Yugoslavia, Iraq and Algeria) *R. secundus* was very common. (The geographical distribution of the two species will form the subject of a subsequent publication.) Statements to the effect that *R. sanguineus* is very common on domestic animals anywhere in the Near East should be carefully re-examined.

The practical importance of these findings lies in the fact that it explains discrepancies in field records. In one instance in the same locality, cows are often covered with the alleged "*R. sanguineus*", whereas the dog is free from the "same" tick, or the contrary. This is due to the fact that cows are parasitised mainly by *R. secundus*, whereas the dog does not attract this species to the same extent.

TABLE I.

The hosts of *R. sanguineus*, *sens. str.*, and *R. secundus* in Israel.

Host	No. of batches examined	No. of females or preimaginal stages examined		% found	
		<i>R. sanguineus</i>	<i>R. secundus</i>	<i>R. sanguineus</i>	<i>R. secundus</i>
Dog	36	124	29	81	19
Cattle	44	8	229	3	97
Sheep	39	9	150	6	94
Goat	38	18	174	9	91
Horse	11	4	32	11	89
Donkey	10	6	22	21	79
Jackal	10	10	22	31	69
Hedgehog ..	19	11	30	27	73

The figures relative to horse, donkey, jackal and hedgehog are small and therefore cannot be considered conclusive.

It might also be concluded that *R. secundus* is much more prevalent in Israel than *R. sanguineus*.

It is obvious that all experiments relating to transmission of disease by alleged *R. sanguineus* should be reevaluated, and it should be determined whether diseases such as Q fever, fièvre boutonneuse, anaplasmosis, etc., which hitherto were considered to be transmitted by *R. sanguineus, sens. lat.*, are transmitted by *R. sanguineus, sens. str.*, or *R. secundus*, or both species. In view of the considerable host specificity, statement of the host origin of specimens used in transmission experiments would give some indication as to whether *R. sanguineus* or *R. secundus* is the suspected transmitter. Unfortunately, authors rarely state the host origin of the material they worked with, and it is therefore impossible to comment on their results. Enigk's (1943) paper includes not only the host origin but also mentions interesting differences in the aptitude to transmit disease. Enigk refers to two different strains of *R. sanguineus, sens. lat.*; his experiments with horse piroplasmiasis were carried out with material taken from a horse in Prilep, Macedonia (his strain A), and from dogs in Tripoli, North Africa (his strain B). He found that (Table 2, p. 219) when imagines of strain A were fed on a horse infected with *Nuttallia equi* and *Piroplasma caballi*, the imagines of the second generation did not infect a clean horse with either parasite, but in an experiment carried out with strain B in which nymphs were fed on the same infected animal, imagines of the first generation transmitted *N. equi* only, while imagines of the second generation transmitted *P. caballi* only. The difference in results in the experiments with the two strains are striking. It is possible that the two strains A and B with which Enigk worked did not belong to the same species. We had no opportunity of examining material from Greece and Tripoli, but in material from Yugoslavia, Turkey and Algeria we found both *R. sanguineus* and *R. secundus*, and it is therefore not improbable that strain B from the dog was *R. sanguineus, sens. str.*, and strain A from the horse, *R. secundus*.

Summary.

The host specificity of *R. sanguineus* (Latr.), 1806, *sens. str.*, and *R. secundus* Feldman-Muhsam, 1952, in Israel was studied.

It was found that 81 per cent. of *R. sanguineus, sens. lat.*, found on the dog was *R. sanguineus, sens. str.*, and 19 per cent. *R. secundus*, whereas on cattle, sheep and goats, 97, 94 and 91 per cent., respectively, were *R. secundus* and the remainder *R. sanguineus, sens. str.*

It is suggested that this situation exists also in other countries in the Near East, since *R. secundus* was very common in material from Algeria, Turkey, Yugoslavia and Iraq.

The problem of transmission of disease by *R. sanguineus, sens. lat.*, should be re-investigated in the light of recent taxonomic data.

References.

- COLAS-BELCOUR, J. & RAGEAU, J. (1951). Tiques de Tunisie: Ixodines.—Arch. Inst. Pasteur Maroc, **4**, pp. 360–367.
- ENIGK, K. (1943). Die Überträger der Pferdepiroplasmose, ihre Verbreitung und Biologie.—Arch. wiss. prakt. Tierheilk., **78**, pp. 209–240.
- FELDMAN-MUHSAM, B. (1952). On the identity of *Rhipicephalus sanguineus* Lat.—Bull. Res. Coun. Israel, **2**, pp. 187–194.
- HOOGSTRAAL, H. (1954). Ticks (Ixodoidea) and their medical relations in the Near East.—J. Egypt. publ. Hlth Ass., **29**, pp. 1–8.
- PANTAZIS, G. P. (1947). The ticks of Greece. [*In Greek.*]—Sci. Yearb. Univ. Athens, 1946–47, pp. 71–182.
- SERGEANT, Ed., DONATIEN, A., PARROT, L. & LESTOQUARD, F. (1945). Études sur les piroplasmoses bovines.—816 pp. Algiers, Inst. Pasteur Algér.
- THEILER, G. (1943). Notes on the ticks off domestic stock from Portuguese East Africa.—55 pp. Lourenço Marques, Estaç. Anti-Malár.
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THE DISTRIBUTIONS OF COCCINELLID EGG BATCHES AND
LARVAE IN RELATION TO NUMBERS OF *APHIS FABAE*
SCOP. ON *VICIA FABAE*.

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In the simplest case of interaction of a parasitic insect with its insect host the life-cycles of the interactants are synchronised, no alternative host is available and the parasite can increase only at the expense of the host.

A more complex type of interaction exists when aphid-eating Coccinellids attack an Aphid like *Aphis fabae* Scop. on beans. The prey undergoes several generations in a few weeks while its predators have but one, or perhaps two, generations a year. The Coccinellids multiply at the expense of many Aphid species throughout the year and any increase in their numbers on, say, bean plots infested with *A. fabae*, may not be attributed entirely to reproduction at the expense of this particular prey species.

It is the purpose of this paper to present additional results from a survey of Coccinellid predators and Aphids on three bean plots to illustrate the different ways in which the predator and prey populations varied, the Coccinellids by immigration, the Aphids by reproduction.

The survey was carried out at Rothamsted during 1952 (Banks, 1955). Although the populations of *A. fabae* on the three plots of *Vicia faba* varied considerably in size and in rates of development and decline, no correlation was found between the numbers of Aphids on a plot and the number of Coccinellids (adults and immature stages) on it. The main factor determining the numbers of adult Coccinellids was considered to be the distance of the plot from nettles harbouring ladybirds which immigrated to the beans. The numbers of Coccinellid eggs and larvae occurring on the beans depended on the numbers of adult Coccinellids which arrived there and not on the numbers of Aphids. The observations suggested that the populations of Coccinellids and of Aphids on these plots varied independently of each other.

It is often stated that adult Coccinellids lay their eggs in places close to the prey and it is assumed, therefore, that the larvae are near their food when they have hatched from the eggs. If female Coccinellids instinctively lay their eggs close to colonies of Aphids, then, in the early stages of the infestations by *A. fabae* when colonies are few, we would expect to find egg batches on aphid-infested stems only; but when all the stems are infested and Aphids very numerous, egg batches would be laid at random. The present study of the distributions of coccinellid egg batches and larvae at various stages of development of the aphid infestations of the beans would, therefore, throw light on the oviposition behaviour of the adult Coccinellids.

Methods.

Details of the methods of estimation of numbers of Aphids and Coccinellids have appeared in two previous papers (Banks, 1954b, 1955). A fixed number of stems in each of the 12 rows of each of the three bean plots was examined regularly at weekly intervals for the duration of the infestations by *A. fabae*, the numbers of such stems so examined being Plot A, 288; Plot C, 384; Plot D,

336. Each stem was examined from the ground upwards and all predators seen were recorded but not removed from the plants. At the same time, the stem was classified according to its degree of infestation by *A. fabae* into one of five classes: without Aphids (O), very light (V), light (L), medium (M) and heavy (H). Estimates of the numbers of Aphids in each of these classes are given in Table I.

TABLE I.

Estimates of numbers of *Aphis fabae* in classes of infested bean stems with other information concerning the aphid infestations.

Class of stem	Plot		
	A	C	D
V	100	97	190
L	984	1769	1511
M	5205	7660	9736
H	12833	13010	19413
Proportion of stems infested in week 7 (%) ..	23	37	54
Mean Aphids per stem in week 7	20	45	93
Week when maximum aphid nos. reached ..	week 13	week 13	week 12
Maximum numbers of Aphids per stem	4676	9639	13958

Three species of Coccinellids were common on the bean plots, *Adalia bipunctata* (L.), *Coccinella septempunctata* L. and *Propylea quatuordecimpunctata* (L.), the first forming approximately 70 per cent. of all the species, while about 70 to 78 per cent. of the eggs appeared to be of this species.

Eggs as well as larvae of all species have been treated together, for many young larvae of the various species could not be distinguished from each other in the field. Larvae were classified as 'just-hatched' (the stage after eclosion, with the young larvae still grouped on and around the empty egg shells, which lasts from a few hours to 24 hours) and as 'older' larvae (mostly 3rd and 4th instars).

Primary migrants of *A. fabae* arrived on the beans during the week ended 21st May (week 6 of the survey). In week 7, the plots differed in their levels of aphid infestation, Plot D having 54 per cent. of the stems infested, Plot C, 37 per cent., and Plot A, 23 per cent. Maximum aphid numbers, attained in week 12 (Plot D) and week 13 (Plots C and A), were in the approximate ratio D:C:A::3:2:1. The maxima were followed by rapid declines, and by weeks 14 (Plot D) and 15 (Plots C and A) the infestations had completely died out.

Distributions of Coccinellid Egg Batches.

Two questions relating to the oviposition behaviour of the adult Coccinellids must be considered; first, before all the stems had become infested, were egg batches laid more frequently on aphid-infested stems than can be explained by chance, that is, was there any significant association between the presence of eggs on a stem and the presence of Aphids. Secondly, when all the stems had become infested, the female Coccinellids could only lay their eggs close

to aphid colonies. We then have to consider whether the egg batches were laid on the stems with the most Aphids, that is, what was the extent of any correlation between the numbers of egg batches and the numbers of Aphids on individual bean stems.

TABLE II.

Mean numbers of coccinellid egg batches per class of stem.

	Class of stem	Mean egg batches per stem for week							
		7	8	9	10	11	12	13	14
Plot A	O	0.07	0.14	0.08	0.08	0	0	—	0
	V	0.09	0.18	0.17	0.22	0.06	0.11	0.04	0
	L	—	—	0.09	0.69	0.15	0.24	0.21	0.08
	M	—	—	1.00	0.50	0.38	0.58	0.33	0.18
	H	—	—	—	1.00	0	1.44	0.57	0.56
Plot C	O	0.14	0.13	0.20	0.27	0	—	0	0
	V	0.17	0.21	0.40	0.45	0.22	0	—	0
	L	0.33	0.36	0.62	0.63	0.30	0.18	0	0.05
	M	—	0	0.75	0.83	0.50	0.60	0.24	0.03
	H	—	—	0.50	0.72	0.67	0.86	0.36	0.38
Plot D	O	0.08	0.06	0.06	0.33	—	—	0	0
	V	0.08	0.06	0.12	0.15	0	—	0	0.03
	L	—	0.14	0.20	0.15	0.21	0.50	0.17	0.11
	M	—	—	0.20	0.49	0.16	0.52	0.43	1.25
	H	—	—	0	0.15	0.21	0.73	0.46	—

The mean numbers of egg batches on each class of stem for the three plots are given in Table II. In the first week of the survey of beans (week 7), 48 to 71 per cent. of all egg batches occurred on uninfested stems, although 46 to 77 per cent. of the stems were infested with Aphids. As more and more stems became infested, the proportion of egg batches on uninfested stems, of course, decreased (Table III) and after week 10 (Plot D), week 11 (Plot C) and week 12 (Plot A), all stems had become infested.

TABLE III.

Distributions of coccinellid egg batches on infested and uninfested stems before all stems had become infested with *Aphis fabae*.

Week	Plot A		Plot C		Plot D	
	% egg batches on Class O	% stems uninfested	% egg batches on Class O	% stems uninfested	% egg batches on Class O	% stems uninfested
7	71	77	59	63	48	46
8	58	63	39	53	30	32
9	38	57	26	44	12	24
10	17	46	8	15	3	2
11	0	19	0	1	—	0

TABLE IV.
Numbers of infested and uninfested bean stems with or without coccinellid egg batches,
before all stems had become infested with *Aphis fabae*.

	Week							
	7		8		9		10	
	eggs present	eggs absent	eggs present	eggs absent	eggs present	eggs absent	eggs present	eggs absent
Plot A Aphids present Aphids absent χ^2 P	6 15	61 206 0.11 0.74	18 25	89 156 0.27 0.60	19 15	103 153 3.52 0.06	37 9	119 123 14.00 <0.001***
Plot C Aphids present Aphids absent χ^2 P	20 34	123 207 0.34 0.56	35 25	146 178 3.07 0.07	78 29	138 139 3.61 0.06	131 13	198 42 4.60 0.03*
Plot D Aphids present Aphids absent χ^2 P	10 14	171 141 2.12 0.15	14 6	214 102 0.001 0.98	32 5	224 75 1.83 0.18	— —	— —

* = significant of association ($P < 0.05$)
*** = highly significant of association ($P < 0.001$)

Regarding the first question mentioned above, the numbers of infested and uninfested stems observed with and without egg batches are given in Table IV for the bean plots for the first three or four weeks of the survey. During weeks 7, 8 and 9, when many stems were uninfested, there were no significant associations of the egg batches with the Aphids ($P > 0.05$).

On Plot D in week 10 all the stems were infested; on Plots A and C, although a few stems remained uninfested in weeks 10 and 11, egg batches were significantly associated with the presence of Aphids, for, during weeks 9–11, the aphid colonies on many stems had become so large that the adult Coccinellids were able to find them readily; eggs were laid more often on such stems, for the beetles tended to stay and feed on the Aphids.

The second question, whether there was a positive correlation between the numbers of egg batches and the numbers of Aphids on bean stems, has been examined by the calculation of linear regressions for those weeks before the aphid populations of the plots started to decline, the two variables being mean egg batches per class of stem (y) and mean Aphids per class of stem (x). To reduce the variability of the data and to permit the inclusion of stems without eggs or Aphids, the transformations $\log(y + 0.001)$ and $\log(x + 0.001)$ have been used to calculate the equation

$$\log(y + 0.001) = b \cdot \log(x + 0.001) - \log a$$

which may be written

$$(y + 0.001) = \frac{(x + 0.001)^b}{a}$$

The results are given in Table V; no regressions could be calculated for Plot A (weeks 7 and 8) and Plot D (week 7), for stems of only two classes occurred. The regressions with the highest values occurred when aphid numbers were at or

TABLE V.

Weekly regressions (b) of mean coccinellid egg batches on Aphids per class of stem.

				Week						
				7	8	9	10	11	12	13
Plot A										
Regression (b)	..	..		—	—	0.100	0.141	0.205	0.424	0.524
S.E. ±	..	..		—	—	0.094	0.030	0.215	0.023	0.066
P.	..	..		—	—	—	<0.05	—	<0.001	<0.05
Plot C										
Regression (b)	..	..		0.047	−0.158	0.071	0.064	0.395	0.787	—
S.E. ±	..	..		0.035	0.279	0.015	0.141	0.033	0.086	—
P.	..	..		—	—	<0.05	—	<0.01	—	—
Plot D										
Regression (b)	..	..		—	0.039	−0.065	−0.023	1.070	0.122	—
S.E. ±	..	..		—	0.050	0.184	0.045	0.483	0.103	—
P.	..	..		—	—	—	—	—	—	—

near their maxima (Plot A, week 13; Plot C, week 12; Plot D, week 11). Three of the regressions are negative and are for those plots where aphid numbers were high (Plots C and D).

The majority of the regressions are positive, indicating that the adult Coccinellids tended to lay their eggs on the most heavily infested stems.

The relative changes in numbers of coccinellid eggs and Aphids on the plots

over the period of the survey may be compared by measuring the extent to which the weekly regressions of each plot are positive.

Common regressions " (\bar{b}) " for each plot have been calculated (Table VI). They are all positive, but the slope is greatest for Plot A, with the lowest aphid population, and smallest (in fact, negligible) for Plot D where the aphid population was largest.

TABLE VI.

"Common" regressions of coccinellid egg batches on Aphids and of older larvae on Aphids, compared with the maximum numbers of Aphids recorded.

Plot	Common regression for egg batches and Aphids (\bar{b})	P.	Maximum Aphid numbers recorded (Aphids per stem)
A	0.229 ± 0.056	<0.01	4676
C	0.102 ± 0.057	<0.05	9639
D	0.005 ± 0.072	>0.05	13958
	For older larvae and Aphids (\bar{b})		
A	0.271 ± 0.050	<0.001	4676
C	0.153 ± 0.044	<0.01	9639
D	0.185 ± 0.070	<0.05	13958

These common regressions may be interpreted in the following way. On any one plot, as Aphids increased by 1.0 (on the logarithmic scale), coccinellid eggs increased by 0.229 (Plot A), 0.102 (Plot C) and 0.005 (Plot D). In other words (taking the antilogarithms), a 10-fold increase in Aphids on a plot was accompanied by an increase of eggs of 69 per cent. (Plot A), 26 per cent. (Plot C) and 1 per cent. (Plot D).

Distributions of older Larvae.

When studying the distributions of larvae on the bean plots, it is necessary to consider the older larvae alone, for the distributions of just-hatched larvae would resemble those of egg batches. The distributions of older larvae on each class of stem, with the mean number of larvae per class of stem, for the three plots are given in Table VII.

Weekly regressions (\bar{b}) of log mean larvae ($\log(y + 0.001)$) on log mean Aphids per class of stem ($\log(x + 0.001)$) have been calculated (Table VIII). All but one of these regressions are positive, 8 of the 17 being significant ($P < 0.05$). Older larvae, therefore, tended to occur more often on stems where Aphids were most numerous.

The average slopes of common regressions (\bar{b}) of the weekly regressions (Table VI) are all positive and significant ($P < 0.05$). Again, the slope is greatest for Plot A where the aphid population was the lowest and the meaning of the common regressions is as follows. As Aphids increased by 1.0 (on the logarithmic

scale) on any of the plots, the older larvae increased by 0.271 (Plot A), 0.153 (Plot C) and 0.185 (Plot D); that is, an increase of 10 times the aphid numbers on any one plot was accompanied by an increase in older larvae of 87 per cent. (Plot A), 42 per cent. (Plot C) and 53 per cent. (Plot D).

TABLE VII.
Mean numbers of older coccinellid larvae per class of stem.

	Class of stem	Week								
		7	8	9	10	11	12	13	14	15
Plot A	O	—	—	0.01	0.02	0.06	—	—	—	0.04
	V	—	—	0.06	0.09	0.10	0.19	0.06	0.06	0.37
	L	—	—	—	0.04	0.28	0.21	0.32	0.42	0.49
	M	—	—	1.00	0.50	0.07	1.00	0.87	0.81	0.91
	H	—	—	—	1.00	1.00	1.28	2.00	2.18	—
Plot C	O	—	0.01	0.08	0.05	—	—	—	0.13	0.18
	V	—	0.01	0.02	0.32	0.40	—	—	1.63	0.44
	L	—	—	0.21	0.30	0.58	0.93	0.40	0.71	0.40
	M	—	—	0.13	0.55	0.61	1.62	1.06	1.14	—
	H	—	—	—	0.61	1.25	2.19	1.28	0.81	—
Plot D	O	—	—	—	—	—	—	0.25	0.62	
	V	—	0.02	0.01	0.04	—	—	0.28	0.99	
	L	—	—	—	0.69	0.16	—	0.67	1.20	
	M	—	—	—	0.08	0.15	0.58	0.67	2.00	
	H	—	—	—	0.39	0.31	0.87	1.31	—	

Discussion.

The changes in numbers of Coccinellids relative to the aphid populations will first be considered.
It was seen that the extent to which the weekly regressions of egg batches on Aphids for each plot were positive, varied inversely with the size of the aphid

TABLE VIII.
Weekly regressions (b) of mean older larvae on Aphids per class of stem.

		Week					
		9	10	11	12	13	14
Plot A							
	Regression (b) ..	0.119	0.190	0.103	0.432	0.703	0.450
	S.E. ±	0.281	0.091	0.102	0.031	0.028	0.049
	P.	—	—	—	<0.001	<0.01	<0.01
Plot C							
	Regression (b) ..	-0.088	0.145	0.425	0.419	0.600	0.121
	S.E. ±	0.177	0.016	0.046	0	0.070	0.046
	P.	—	<0.01	<0.01	<0.001	—	<0.05
Plot D							
	Regression (b) ..	—	0.283	1.142	2.812	0.078	0.060
	S.E. ±	—	0.202	0.413	0.599	0.036	0.021
	P.	—	—	<0.05	—	—	—

populations on the plots. Thus on Plot D, where the Aphids were always very numerous, egg-laying by the Coccinellids could not keep pace with the high rate of aphid increase; the common regression, although positive, was not significant; that is, although there was a tendency for the eggs to occur more often on the stems with the most Aphids, the results were so variable that any correlation could be ascribed to chance. On Plots C and A, however, Aphids increased less rapidly and oviposition by the ladybirds was at a higher rate than on Plot D. The common regressions were positive and significant, the value of the regression and its significance level being higher where the Aphids were fewer and had the lower rate of increase (Plot A).

The degree of correlation between the coccinellid egg batches and Aphids (the values of the common regressions), therefore, appeared to be determined by the rate of increase of the aphid numbers. A situation may be imagined in which the Aphids multiplied so slowly that the numbers of coccinellid eggs could have increased at the same rate. That they did not on any of the plots considered here is because the egg numbers varied directly with the numbers of adult Coccinellids, which increased *additively* (by immigration to the beans) and independently of the aphid numbers which increased *multiplicatively* (by reproduction) and at a much higher rate. In the situation imagined above, the rate of increase of coccinellid eggs by addition would have to equal the rate of increase of the Aphids by multiplication.

Some entomophagous Coccinellids are restricted to a particular kind of prey (Schilder & Schilder, 1928; Thompson, 1929), notably those species predacious on Coccids and mites. Balduf (1935) noted that the small species of Coccinellids exhibit a noticeable tendency towards a parasitic relationship with the larger Coccids. Clausen (1940) has pointed out that while most Coccinellids may be regarded as predators, some species have developed habits similar to those of parasites, for a specialisation in oviposition behaviour is combined with a restriction to a particular food. Thus *Rodolia cardinalis* (Muls.), which attacks *Icerya purchasi* Mask., lays its eggs upon the body of the female Coccid or on the egg mass, and the larva preys on this one host whose progeny usually suffice for the whole development of the predator. *Rodolia limbata* (Motsch.), referred to by Clausen (*loc. cit.*) as *Novius limbatus* Mats., attacks the enormous Coccid, *Drosicha corpulenta* (Kuw.), in Japan, sometimes laying its egg beneath the scale, the larva attaching itself to the body of the host (Clausen, *loc. cit.*).

Other Coccinellids, particularly the aphid-eating forms, are less specialised in their feeding and oviposition behaviour, and although they usually lay their eggs in surroundings where the prey occurs, they have been observed to oviposit in places where there is no prey. Thus, *Hyperaspis vinciguerrae* Capra, a predator of mealybugs in Egypt (Hafez & El-Ziady, 1952) has been seen to lay its eggs in places where the newly-hatched larvae had no prey to feed on (El-Ziady, private communication). At Harpenden in April 1952 *Coccinella septempunctata*, emerging from hibernation in grass, laid many eggs on clover and grass leaves and on cigarette cartons although no Aphids were present in the surroundings (Banks, 1954a). Similar observations were made by Hawkes (1920) for *Adalia bipunctata*.

It was suggested at the beginning of this paper that, if female Coccinellids instinctively lay their eggs close to aphid colonies, then, in the early stages of infestations by *A. fabae* when aphid colonies are few, egg batches may be expected on aphid-infested stems only; when all the stems are infested, egg batches will be laid at random.

This argument is not supported by the results of the survey for, during the early stages of the three infestations, any association of coccinellid egg batches with the aphid-infested stems was attributable to chance; but when the infestations had reached an advanced state and all stems were infested, the egg batches

tended to occur most frequently on the stems with the most Aphids. The results suggest, therefore, that the aphid-eating Coccinellids of the species considered here do not need the stimulus of the presence of Aphids before laying their eggs on beans; this is also the impression one gets during fieldwork and the behaviour of the various species does not seem to differ in this respect.

It is, of course, possible that the females laid their eggs on infested stems and then themselves ate the few Aphids present, so that an observer recorded the eggs on uninfested stems, but this suggestion is not supported by observation; for example, on Plot D, oviposition occurred before the arrival of any Aphids, for egg batches and well-developed larvae were found on the beans during week 6 when Aphids first arrived (Banks, 1955).

The correlation of numbers of egg batches with numbers of Aphids when the infestations are well advanced is explained by the concentration of the adult Coccinellids on well-infested stems where they would tend to stay to feed on the Aphids and probably to lay their eggs.

The positive correlations between the older larvae and Aphids were to be expected, for the young larvae, after dispersal from the egg shells, would wander until they encountered an aphid colony. But the correlations were not always significant; the eggs from which the larvae hatched were not always laid close to Aphids and larvae would probably have stayed on the nearest infested stem rather than on the most heavily infested stem in the vicinity.

When aphid-infested stems are few, the young larvae might not be able to find them and under such conditions many probably die of starvation and exhaustion unless they can live for the time being on other food such as coccinellid eggs and larvae or other small insects. Those larvae able to find a small amount of food quickly would probably be able to live longer and thus be able to search a larger number of plants to find a food supply sufficient for their growth requirements; and those larvae hatching from eggs laid on infested stems might start with an advantage. The proportion of young larvae able to reach an aphid colony is probably higher when the aphid infestation on a bean plot is well-advanced than when it is in its early stages.

Summary.

Further analysis of results obtained from a study of populations of Coccinellids on three plots of *Vicia faba* infested with *Aphis fabae* Scop. at Rothamsted during 1952 are presented. The distributions of coccinellid egg batches and older larvae (mostly 3rd and 4th instars) on bean stems of five arbitrary classes of aphid infestation, emphasise the differences in the manner of increase of the predator and prey populations considered here; at the same time, the results throw light on the oviposition behaviour of the adult Coccinellids.

The degree of correlation between coccinellid egg batches and Aphids on the plots (as indicated by regression analysis) varied inversely with the size of the aphid populations on the plots. On one plot, where Aphids were extremely numerous, this correlation was negligible; on the two other plots, where Aphids were less abundant, the correlation was more marked, being highest at the plot where the aphid numbers were lowest. The degree of correlation between egg batches and Aphids was determined apparently by the rate of increase of aphid numbers. It is pointed out that while these coccinellid populations increased additively (by immigration of ladybirds to the beans), populations of *A. fabae* increased multiplicatively (by reproduction) and at much higher rates.

During the early stages of the aphid infestations on the bean plots, when aphid-infested stems were comparatively few, there was no statistically significant association between coccinellid eggs and the presence of Aphids on the bean stems; but when all stems had become infested, egg batches tended to occur

most frequently on the stems with the most Aphids. From these and other observations it is concluded that the female Coccinellids do not need the stimulus of the presence of Aphids before laying their eggs on beans, and that they concentrate on well-infested bean stems where they tend to stay and feed on the Aphids and probably oviposit on those stems. The distributions of older coccinellid larvae (3rd and 4th instars) indicate that they, too, tend to concentrate on well-infested stems.

The oviposition habits of the female Coccinellids are discussed in relation to the feeding problems of the newly-hatched larvae.

Acknowledgements.

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References.

- BALDUF, W. V. (1935). The bionomics of entomophagous Coleoptera.—220 pp. St. Louis, Swift.
- BANKS, C. J. (1954a). Random and non-random distributions of Coccinellidae.—J. Soc. Brit. Ent., **4**, pp. 211-215.
- BANKS, C. J. (1954b). A method for estimating populations and counting large numbers of *Aphis fabae* Scop.—Bull. ent. Res., **45**, pp. 751-756.
- BANKS, C. J. (1955). An ecological study of Coccinellidae (Col.) associated with *Aphis fabae* Scop. on *Vicia faba*.—Bull. ent. Res., **46**, pp. 561-574.
- CLAUSEN, C. P. (1940). Entomophagous insects.—688 pp. New York & London, McGraw-Hill.
- HAFEZ, M. & EL-ZIADY, S. (1952). Studies on the biology of *Hyperaspis vinci-guerrae* Capra, with a full description of the anatomy of the fourth stage larva (Coleoptera: Coccinellidae).—Bull. Soc. Fouad I^{er} Ent., **36**, pp. 211-246.
- HAWKES, O. A. M. (1920). Observations on the life-history, biology and genetics of the lady-bird beetle, *Adalia bipunctata* (Mulsant).—Proc. zool. Soc. Lond., **1920**, pp. 475-490.
- SCHILDER, F. A. & SCHILDER, M. (1928). Die Nahrung der Coccinelliden und ihre Beziehung zur Verwandtschaft der Arten.—Arb. biol. Reichsanst., **16**, pp. 213-282.
- THOMPSON, W. R. (1929). On the relative value of parasites and predators in the biological control of insect pests.—Bull. ent. Res., **19**, pp. 343-350.
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R
A NEW SPECIES OF *MEGASTIGMUS* (HYM.: CHALCIDOIDEA)
FROM BRITISH SOMALILAND.

By N. W. HUSSEY, B.Sc., Ph.D.

E. 11. 11.

Difficulty is being experienced in obtaining natural regeneration of *Juniperus procera* in the Daloh Forest, Erigavo, British Somaliland due to infection of the seed by an unidentified species of *Megastigmus*. In 1953, Mr. A. R. Tribe succeeded in breeding specimens from infested seed, and this material, together with a subsequent collection by Mr. J. J. Lawrie in January 1954, has been used as the basis of the following description.

***Megastigmus somaliensis*, sp.n.**

Female.—Body length 2.7–3.6 mm.; abdomen 1.3–1.5 mm.; ovipositor 1.5–1.9 mm.

Head from above transversely oval; vertex evenly convex transversely rugulose behind ocelli; genal area finely reticulate; malar space slightly less than half height of compound eye which is shallowly convex; occipital carina sharp evenly arcuate; ocelloccipital line subequal to ocellocular line, less than half posterior ocellar line; antennal scrobe deep not attaining anterior ocellus; scape equal to combined lengths of pedicel, ring-joint, first funicle segment (FI) and half second funicle segment (FII); pedicel wider than FI, funicular segments of almost equal width but decreasing slightly towards tip; vestiture on head stout, black hairs on upper half of head; finer, white ones on lower face and genae. Pronotum from above distinctly wider than long bearing sharp transverse rugae less defined laterally, flange on anterior dorsal margin weak with feeble emargination; mesopraescutum and parapsides with strong transverse arcuate rugae (but less marked than on pronotum); axillae with fine oblique aciculations; scutellum truncate anteriorly, transversely shingled to the indistinct frenal furrow (transverse line), smooth and shining behind with fine longitudinal rugae, vestiture on thorax sparse and coarse, scutellar hairs (7–8) in arched row above lateral margin (fig. 1,a). Propodeum (fig. 1,b) irregularly transversely rugose with fine, weak, converging carinae as in male, without median carina, groove below propodeal spiracle weakly defined; abdomen weakly compressed laterally; ovipositor strongly arched upwards at base.

Forewing with 11 to 13 sub-marginal bristles; radius and stigma as in fig. 1,d. Colour, yellow-brown. Face yellow-brown becoming pitchy on clypeal and genal areas darker on vertex; remainder of head dull yellow-brown; scape and pedicel yellow-brown beneath; remainder of antenna dark brown. Pronotum yellow, anterior and posterior flanges darker but paler at sides; mesopraescutum yellow-brown but lateral borders yellow sometimes with two anterior brown spots; parapsides with anterior half yellow-brown remainder yellow; axillae yellow-brown excepting yellow inner angle; scutellum yellow with indistinct yellow-brown patch anteriorly and sometimes a transverse band of yellow-brown anterior to frenal furrow; thoracic sutures pitchy, metanotum brown; propodeum yellow-brown with spiracular groove darker. Legs entirely light yellow-brown. Abdomen brown above and below with posterior margins of tergites 2–6 narrowly yellow-brown dorsally, wider and yellow laterally. Ovipositor sheath dark brown.

Vestiture mostly pale but darker on upper half of head and thoracic dorsum. Stigma with no surrounding infuscation.

Male.—Body length 3.5–4.3 mm.; abdomen 1.4–2.0 mm.

Surface sculpture generally as in female but converging carinae on propodeum more distinct. Scape equal to combined lengths of pedicel, ring-joint, FI and one-third FII.

Forewing with 12 or 13 sub-marginal bristles; radius and stigma as in fig. 1, c.

Colour, face yellow becoming pitchy in clypeal and genal areas, vertex yellow-brown, dark brown behind eyes; scape yellow-brown below remainder of antenna



Fig. 1.—*M. somaliensis*, sp.n. a, scutellum; b, propodeum of female; c, stigma of male forewing; d, stigma of female forewing.

dark brown. Prothorax light yellow becoming lighter laterally; mesopraescutum, parapsides and axillae pale yellow-brown with darker central patches; scutellum yellow-brown. Metanotum yellow. Propodeum yellow but spiracular groove and area proximal to abdomen dark brown. Pro- and mesocoxae basally, metacoxae entirely, dark brown, infuscations on outer surface of fore and hind femora dark brown, remainder of legs light yellow-brown. Abdomen dark brown above, lighter below, the lateral margins of tergites III to V with faint yellow-brown bands.

The colour of the coxae is very variable. In some specimens the whole segment is dark brown and in others yellow-brown.

Type and paratype material of *M. somaliensis* has been deposited in the British Museum (Natural History), London. Further paratype specimens are in the author's collection at the Department of Agricultural and Forest Zoology, University of Edinburgh.

In the British Museum collections there are two specimens, collected by Dr. H. Scott on giant juniper at Mt. Chillalo, Digalla, Abyssinia at about 9,000 ft., which appear to belong to this species.

M. somaliensis is the first recorded species to attack the seed of *Juniperus* in Africa but three species are known on this host in Europe. *M. bipunctatus* (Swederus) and *M. kuntzei* Kapuściński from *Juniperus communis* and, according

to Makhnovskii (1952), *M. juniperi* Nikol'skaya on *J. seravshanica*, *J. semiglobosa* and *J. turkestanica*. *M. bipunctatus* has for long been considered parasitic but Milliron (1949) has put forward an argument, based on the literature, which suggests that it is, in fact, phytophagous.

There is in all probability some confusion between these species as Kapuściński (1946) does not differentiate his species from *M. bipunctatus* and Nikol'skaya (1952) makes no reference to *M. kuntzei* in her key to the genus. Through the kindness of Dr. Jaczewski, Director of the Zoological Institute, Polish Academy of Sciences, Warsaw, I have been able to examine paratype material of *M. kuntzei* which is separable from *M. bipunctatus* on propodeal characters. In both species the propodeum is punctate (cf. *M. somaliensis* fig. 1,b) and in *M. bipunctatus* there is a median carina on the posterior half which is absent in *M. kuntzei*. *M. juniperi* is known only from Nikol'skaya's key but appears distinct from the other three species as the ovipositor is as long as the abdomen, whereas it is shorter in *M. bipunctatus* and *M. kuntzei* and longer in *M. somaliensis*.

The infested seed of *J. procera* from the Daloh Forest also yielded specimens of an unidentified species of *Bracon* (Hym.) which is the first record of a parasitic association between the Braconids and *Megastigmus*.

References.

- KAPUŚCIŃSKI, S. (1946). *Megastigmus kuntzei* n.sp. (Hymenoptera, Chalcididae) destructive insect feeding on seeds of common junipers (*Juniperus communis* L.). [In Polish with English summary.]—Trav. Inst. polon. Rech. for., (A) no. 47, 129 pp.
- MAKHNOVSKIĬ, I. K. (1952). Improving the health of juniper forests in Uzbekistan. [In Russian.]—Lesn. Hoz., 5, pp. 62–65.
- MILLIRON, H. E. (1949). Taxonomic and biological investigations in the genus *Megastigmus* with particular reference to the taxonomy of the Nearctic species (Hymenoptera: Chalcidoidea: Callimomidae).—Amer. Midl. Nat., 41, pp. 257–420.
- NIKOL'SKAYA, M. N. (1952). Chalcids of the fauna of the U.S.S.R. (Chalcidoidea). [In Russian.]—Opred. Faune SSSR, no. 44, 575 pp.
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2
TWO NEW SPECIES OF THE GENUS *PARANASTATUS* MASI
(HYM. EUPELMIDAE) FROM FIJI.

By R. D. EADY

Commonwealth Institute of Entomology.

E.M.N.

Early last year five females of a species of Eupelmid were received from Mr. B. A. O'Connor of the Department of Agriculture in Fiji, where they had been bred in the previous November from eggs of the Phasmid, *Graeffea crouanii* (Le Guillou). Although this Phasmid, which is a pest of the coconut crowns, had been bred many times before, no such parasite had occurred previously. As this species was unknown to the author, more material was requested. Some specimens were sent to the Entomology Research Branch, U.S. Dept. of Agriculture, where Dr. B. D. Burks and Dr. C. F. W. Muesebeck were kind enough to compare them with the collection in the U.S. National Museum; the species was not represented there, nor known from the literature. More material of the same species, including two males, bred out in February, was received soon afterwards, and there was then no doubt that the species belonged to the distinctive but little known genus *Paranastatus* Masi. The species is apparently widely distributed in Fiji. While a description of this species was being prepared, another consignment of material from the same locality revealed the existence of a further species of the same genus.

The genus *Paranastatus* has been known hitherto only by the two species *P. egregius* Masi and *P. violaceus* Masi, three specimens of each having been taken by the Percy Sladen Trust Expedition to Seychelles 1908. The types of these species are in the British Museum, but no further material seems to have been discovered and their hosts are unknown.

Family EUPELMIDAE.

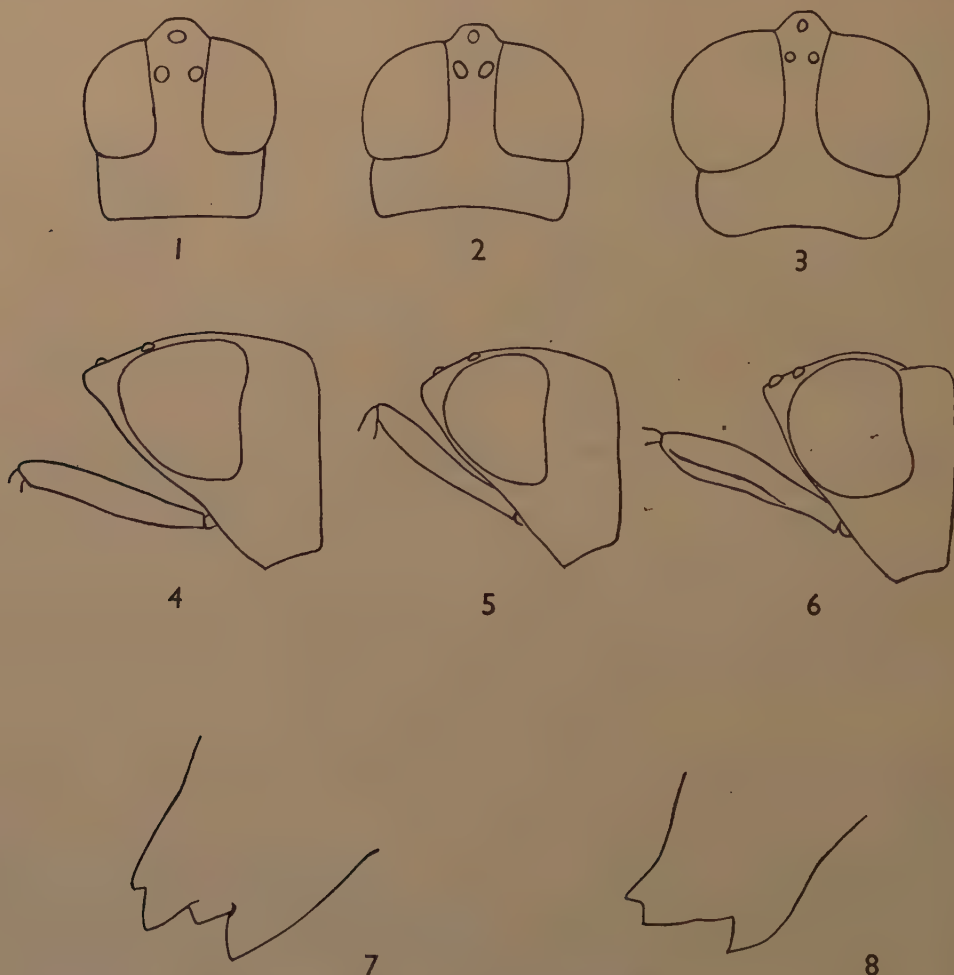
Genus ***Paranastatus*** Masi.

Paranastatus Masi, 1917, Novit. zool., 24, p. 164.

***Paranastatus nigriscutellatus*, sp. n.**

Female.—Head: Viewed from above (fig. 1) it is a little longer than broad, with the narrow fronto-vertex projecting distinctly beyond the anterior curve of the eyes; the latter appear as two large quadrants occupying the greater area of the dorsal surface; the head is parallel behind the eyes and produced back to a distance equal to half the dorsal length of the eye. Ocelli in a triangle in which the distance between the centre of the anterior ocellus and a line joining the centres of the lateral ocelli is a little greater than the distance between centres of the lateral ocelli, the proportions being 1.25:1. Vertex behind the ocelli is smooth and shining, metallic greenish-purple or violet, with sparse, almost obsolete punctures, each with a short fine hair; between the ocelli the surface is weakly coriaceous and metallic green. Occiput hollowed, coriaceous, bluish-green. Viewed laterally (fig. 4) the head is sub-triangular, the vertex slightly convex, forming an acute angle anteriorly with the long straight frons a little in front of the anterior ocellus, and posteriorly joining the occiput at an angle very little greater than a right angle; the other acute angle formed by the frons and the occiput is blunted by the oral opening. The temples are smooth and shining, bluish-green, alutaceous; cheeks golden-green, with a distinct fovea

in the upper half, behind and below the eye; the lower half is buccate with sparse short white hairs. The eyes are large and appear hemispherical in this aspect. Viewed anteriorly the head is longer than broad, the greatest distance across the buccate lower half of the long cheeks being little less than the greatest distance across the eyes (proportion approximately 1:1.25. The length of the



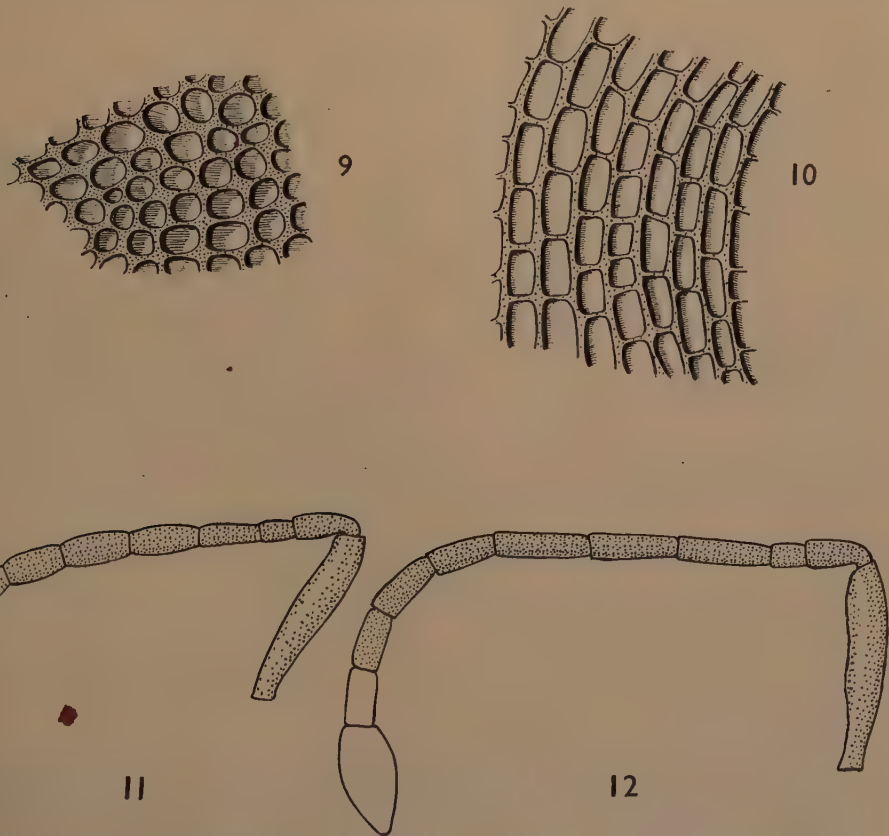
Figs. 1-6.—Head in *Paranastatus*: dorsal view of, (1) *nigriscutellatus*, sp.n.♀, (2) *violaceus* Masi ♀, (3) *verticalis*, sp.n.♀; lateral view of, (4) *nigriscutellatus*, sp.n.♀, (5) *violaceus* Masi ♀, (6) *verticalis*, sp.n.♀.

Figs. 7-8.—Left mandible of, (7) *nigriscutellatus*, sp.n.♀, (8) *verticalis*, sp.n.♀.

cheek is nearly two thirds that of the eye, viewed anteriorly. Frons mainly shining coriaceous, coppery green, but closely and deeply punctate in dorsal region just below the sharp anterior angle. Antennal grooves shallow; antennae inserted just below the line joining the lower margins of the eyes; face, below this, weakly raised to level of buccate half of cheeks, the raised area declining and diminishing upwards to narrow acute apex, flanked by the merging antennal grooves, at a point a little above half way between the antennal insertion and the angle of the fronto-vertex.

Oral opening wide: mandibles quadridentate; first and third teeth small, second and fourth large (fig. 7). Maxillary palpi four-segmented, last segment as long as any two preceding segments together. Labial palpi three-segmented, basal segments very short and thick; first segment with apical width more than twice the length, second segment with width more than twice the length, third segment pointed apically and longer than broad.

Thorax: Prothorax shining alutaceous, purple dorsally, purplish green laterally, with distinct dorsal longitudinal medial suture. Mesoscutum hollowed, shining alutaceous, purplish-copper, bluish-green posteriorly. Scutellum and axillae black, matt, very closely and minutely punctate-reticulate (fig. 9); scutellum acute



Figs. 9-10.—Sculpture of scutellum of, (9) *nigriscutellatus*, sp.n.♀, (10) *violaceus* Masi ♀.

Figs. 11-12.—Left antenna of, (11) *nigriscutellatus*, sp.n.♀, (12) *verticalis*, sp.n.♀.

anteriorly, with very narrow base (axillae not quite touching), broad and rounded posteriorly. Dorsellum sloping, smooth and shining, coppery. Mesopleura alutaceous to weakly coriaceous, purple and bluish-green. Propodeum flattened, very short medially, long and broad laterally, and produced posteriorly at the sides beyond the suture which divides the propodeum from the first segment of the gaster, coriaceous, purplish-copper; spiracles very large and broadly oval.

Abdomen: The gaster is narrow basally, broadening posteriorly with the apex rounded; dorsally alutaceous purplish-bronze, with metallic green posteriorly; first segment centrally whitish above, ventrally with basal sternites white. Terebra concealed.

Length of head, thorax, and abdomen together 2.75 mm.

Antennae (fig. 11): Scape long, reaching to the apex of the projecting fronto-vertex, laterally flattened and bowed; pedicel long, as long as fourth segment (post-annellus) and about equal to fifth, third segment (annellus) twice as long as broad, and more than half the length of the pedicel, seventh segment with length a little more than twice the breadth, eighth to tenth segments a little longer than broad; club broader, with three fused segments. Scape and pedicel are metallic greenish-fuscous, with black hairs; club and preceding two segments (9 and 10) white with white hairs; remaining segments black with black hairs.

Legs: Middle and hind coxae and trochanters white; hind legs with femora yellow basally, brownish in apical half; tibiae and tarsi yellow; middle legs with femora fuscous externally and dorsally, pale stramineous internally towards base; tibiae stramineous; tarsi yellow. Front femora expanded in middle, metallic fuscous, violet externally and fuscous internally; fore tibiae stout, basally lightly infusate, apically yellow; tarsi and trochanters yellow.

Wings: Forewings completely and closely hairy, very lightly infusate, with a small sub-hyaline patch below distal portion of sub-costa, and more strongly infusate at extreme base; post-marginal vein less than half length of marginal vein, and a little more than twice as long as radius. Hind wings hyaline, more sparsely hairy, and with a small glabrous patch at extreme base.

Male.—This differs from the female as follows. Vertex, temples and cheeks, shining coriaceous, violet, mixed with coppery-green. Mesoscutum hardly impressed, coriaceous, shining greenish-violet. Scutellum less narrowed basally; axillae and scutellum weakly shining, dark violet or purple, scaly-reticulate. Mesopleura weakly coriaceous or alutaceous, violet-black anteriorly, dark bluish-green posteriorly. Gaster without pale area basally. Antennae with only the club and the preceding segment white, segment 9 greyish-white with black hairs. Legs with all trochanters white; coxae white only at the apices; hind tibiae broader and laterally rather flattened, pale yellow to straw-yellow with a longitudinal brownish streak; all femora metallic fuscous or fuscous-purple.

Material.—*FM*: Tavuni, 5 ♀♀, *ex* eggs of *Graeffea crouanii*, xi. 1953; Savu Savu, 2♂♂, 9♀♀, *ex* *Graeffea crouanii* eggs, ii. 1954; B. A. O'Connor. Type ♀, allotype ♂, Savu Savu, ii. 1954. Type, allotype, and four paratypes in British Museum (Natural History); one paratype in U.S. National Museum; one paratype sent to Dr. L. Masi.

***Paranastatus verticalis*, sp.n.**

Female.—Head: From above the overall length distinctly less than the width (fig. 3), the eyes shorter in proportion, broader and more prominent, and the narrowest part of the vertex between them less than in the previous species. Vertex, between the eyes, rugulose, rather dull, black; temples smooth and shining metallic violaceous-green. Ocelli in an isosceles triangle; distance between centre of anterior ocellus and a line joining the centres of the lateral ocelli, greater than the distance between the centres of the lateral ocelli, the proportions being 1.5:1. Occiput hollowed. Viewed laterally (fig. 6) the vertex appears more raised behind the eye than in *nigriscutellatus*, and rather flattened between the hind margin of the eye and the occiput. Otherwise the head is shaped as in other species of the genus. Cheeks hollowed below the eyes, reticulate, coppery or coppery-green; temples smooth or weakly alutaceous towards lower edge. Viewed anteriorly, the eyes are more prominently rounded than in *nigriscutellatus*; face reticulate-coriaceous, coppery, with close fringe of pale hairs above clypeus. Mandibles tridentate (fig. 8). Maxillary palpi as in preceding species; labial palpi with basal segments a little longer and less stout.

Thorax: Prothorax dorsally smooth, shining, bluish-green, with longitudinal

medial suture; ventrally and laterally yellowish-brown. Mesoscutum smooth, shining, brownish-violet. Scutellum and axillae reticulate, orange-brown; scutellum acute anteriorly, broadening posteriorly, with obtuse apex. Dorsellum vertical, short, smooth, orange-brown. Mesopleura smooth, alutaceous near margins, brown. Mesosternum alutaceous, brown. Propodeum flattened, very short medially, long and broad laterally, produced posteriorly on each side, coriaceous, greenish-violet or purple; spiracles large, very broadly oval.

Abdomen: Gaster shaped as in previous species; dorsally with obsolete reticulate sculpture, yellowish-brown, darker brown basally; ventrally dark brown, with the basal sternite whitish.

Length of head, thorax and abdomen together, 2.5 mm.

Antennae (fig. 12): Scape long, reaching distinctly beyond fronto-vertex angle, strongly laterally compressed, particularly towards base; segments 4 to 6 long, 4 hardly perceptibly longer than 5 or 6 and equal to pedicel together with annellus; pedicel about equal to segment 9. Scape metallic fuscous-green, sometimes purplish-copper dorsally, pedicel and annellus metallic green; tenth segment and base of three-segmented club white, apex of club yellowish; remaining segments of antennae black.

Legs: All coxae and trochanters whitish, pure white on hind legs; all femora brown; front and middle tibiae and tarsi brownish-yellow; hind tibiae yellow, dorsally with longitudinal pale streak; hind tarsi yellow.

Wings: Forewings infusate except for pale transverse band below distal half of sub-costa; closely pubescent. Hind wings hyaline.

Male.—Compares with female as follows:—Dark fuscous violet; scape and pedicel greenish, tenth segment and club ivory, remainder black; hind trochanters and apex of hind coxae whitish, fore trochanters pale brown, middle trochanters yellow; all femora metallic fuscous; all tibiae pale yellow, externally with longitudinal white streak, very conspicuous on middle and hind legs; all tarsi yellow. Head, with occipital margin strongly excavate medially; vertex dull coriaceous black between eyes. Mesoscutum, mesopleura, mesosternum, alutaceous; scutellum and axillae reticulate; dorsellum convex and rugulose; propodeum alutaceous. Gaster with obsolete sculpture, dark fuscous violet. Forewings lightly infusate, with darker patch beneath junction of sub-costa and marginal vein, and a hyaline transverse band below middle of sub-costa.

Material.—FIJI: Savu Savu, 11 ♀♀, 1 ♂, *ex* eggs of *Graeffea crouanii*, vi. 1954, B.A. O'Connor. Type ♀, allotype ♂ and 6 paratypes in British Museum (Natural History); one paratype each sent to U.S. National Museum and Dr. L. Masi.

Key to females of *Paranastatus*.

1. Gaster without white-marked ventral segments. Antennae with segments 8–10 whitish; club white or brown. Middle coxae yellowish-brown, hind coxae brown or violet. Temples and vertex between the eyes, shining, rather weakly rugulose. Mandibles quadridentate. Head dorsally with distance from apex of fronto-vertex to a line joining the posterior margins of the temples (length) a little less than the greatest width across the eyes (breadth); temples slightly convex and sub-parallel behind the eyes; occipital margin concave (fig. 2). (Seychelles) 2.

Gaster white marked ventrally towards base. Antennae with segment 10 or 9 and 10 only, white; club white. Middle and hind coxae white. Temples smooth and shining; vertex between eyes smooth and shining, or dull rugose. Mandibles tri- or quadridentate. Head dorsally a little longer than broad, or distinctly broader than long; temples long, straight and parallel behind eyes (fig. 1), or shorter, distinctly convex and slightly converging posteriorly (fig. 3); occipital margin straight (fig. 1), or very distinctly excavate (fig. 3). (Fiji) 3.

2. Forewings distinctly infusate, with a pale hyaline transverse band basal of middle, and a pale area basally below middle of sub-costa. Scutellum dark yellow. Head dorsally, and apex of abdomen, metallic green. Hind coxae brown. Club of antenna mostly brown *egregius* Masi

Forewings less deeply, but completely infusate. Scutellum brown. Head dorsally, and apex of abdomen, greenish-violet. Hind coxae violet. Club of antenna at most brown at apex *violaceus* Masi

3. Forewings very lightly, but completely, fuscous-tinged. Scutellum black, not shining, very closely and finely punctate-reticulate (fig. 9). Dorsellum sloping, visible from above as a triangular sclerite. Head (figs. 1 & 4) slightly longer than broad; temples straight and parallel; occipital margin straight; temples and vertex between eyes smooth and shining. Mandibles quadridentate (fig. 7). Antennae with ninth and tenth segments and club white; segments five to eight shorter and thicker, greatest width more than one half the length; fourth segment shorter than pedicel with third segment; scape reaching to apex of fronto-vertex, laterally compressed, but not broad (fig. 11) *nigriscutellatus*, **sp.n.**

Forewings distinctly infusate, with a paler transverse band below distal portion of sub-costa. Scutellum scaly-reticulate (similar to *violaceus* Masi, fig. 10), orange-brown. Dorsellum vertical, short, invisible from above. Head (figs. 3 & 6) distinctly broader than long, eyes more prominent; temples distinctly convex and converging slightly posteriorly; occipital margin distinctly excavate; temples smooth and shining, vertex between eyes rugose and dull. Mandibles (fig. 8) tridentate. Antennae with tenth segment and club white, segments five to eight longer, greatest width distinctly less than half the length (segments five and six about three times as long as broad); fourth segment as long as pedicel with third segment; scape reaching beyond apex of fronto-vertex, laterally compressed and broad (fig. 12). Hind tibiae with pale whitish streak dorsally *verticalis*, **sp.n.**

NOTE: In this key it may be observed that *egregius* Masi is included in a section with quadridentate mandibles; Masi (1917) described the species as having bidentate mandibles. A closer examination of the type, and removal of some of the mixture of gum and dirt that partially obscured the mouth-parts, revealed that the mandibles of the female were distinctly quadridentate. Those of the male are apparently bidentate.

Key to males of *Paranastatus*.

1. Vertex shining, coriaceous or weakly reticulate; occipital margin dorsally slightly concave 2.

Vertex dull coriaceous; occipital margin dorsally distinctly excavate. (Temples short, convex, and converging posteriorly; mandibles tridentate; coxae and femora metallic fuscous, trochanters paler, middle and hind tibiae with longitudinal white streak dorsally; antennae with tenth segment and club white) *verticalis*, **sp.n.**

2. Legs yellow. Temples rather short, convex, and slightly converging posteriorly. Mandibles bidentate *egregius* Masi

Legs with coxae metallic fuscous, apically white; all trochanters white; all femora metallic fuscous or fuscous-purple; hind tibiae pale yellow to straw-yellow. Temples longer, weakly convex, sub-parallel. Mandibles quadridentate *nigriscutellatus*, **sp.n.**

NOTE: The male of *violaceus* Masi is not known, but would probably run down between *egregius* and *nigriscutellatus* in the above key. It is possible that the legs may be entirely fuscous without white markings, and the head may resemble *egregius* more closely in shape, with distinctly quadridentate mandibles like *nigriscutellatus*.

Acknowledgements.

I wish to thank Dr. B. D. Burks and Dr. C. F. W. Muesebeck for their examination of some specimens of this material, and their search of recent literature in America; also Mr. B. A. O'Connor for his assistance in providing so promptly further specimens as they became available.

Reference.

MASI, L. (1917). Chalcididae of the Seychelles Islands.—Novit. zool., **24**, pp. 121–230.

AN INEXPENSIVE, EASILY-CONSTRUCTED, CONTROLLED TEMPERATURE AND HUMIDITY ROOM FOR MAINTAINING INSECT COLONIES.

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The need having arisen for a small, conveniently situated warm room for the maintenance of mosquitos in a constant environment, the cabinet described below was constructed by the authors at a relatively small cost, and set up in a laboratory-class room (35 ft. \times 45 ft.). The warm room, being detached and moveable, entailed no structural alterations or installations.

Construction.

The framework of the warm room was constructed with 6-ft. lengths of commercially available 14-gauge angle steel (3 in. \times 1 in.) with $\frac{3}{8}$ -in. holes drilled at $1\frac{1}{4}$ -in. centres. These were bolted together to form a 6-ft. cube. On one side was a 4-ft. \times 3-ft. annexe, which formed an insect baffle chamber (see fig. 1). On to this framework were bolted the walls and ceiling; these were formed from 6-ft. \times 3-ft. sheets of densely compressed wood fibre board * $\frac{3}{16}$ -in. thick on the outside, and similar size sheets of a loosely compressed cane fibre board * $\frac{1}{2}$ -in. thick on the inside. Between these two sheets a narrow air space was maintained by means of washers between the sheets wherever they were bolted together. The floor consisted of the densely compressed wood fibre board with animal felt and paper beneath.

The doors with completely surrounding jambs were factory-made to specification, to fit the 6-ft. \times 3-ft. panels of the warm room and the insect baffle chamber. They were swung from $\frac{3}{4}$ -in. off-set refrigerator hinges, and thermally sealed in the jambs with strip-rubber refrigerator-door gaskets. The inner door had a core of loosely compressed cane fibre board, and was surfaced with waterproof plywood; the outer door was hollow (the details of the relationship between the door and its jamb, the hinges, and the handles and catches are given in fig. 2.).

To form a moisture barrier on the warm side of the insulation (loosely compressed cane fibre board), all joints were sealed with putty or with adhesive tape. All internal walls, doors and ceilings were thoroughly painted, first with two coats of sealer, and then with two coats of pale cream, non-porous, semi-flat paint, and the floor was sealed with a proprietary floor-polishing wax.

Equipment.

Within the warm room (see fig. 3) a bench occupied one wall with a series of shelves on the adjoining wall; bench and shelves were formed from 2-in. timber, screwed at 3-in. centres on to angle steel framework. The source of light was a cold cathode, 40-watt, 4-ft. long, fluorescent tube fixed to the ceiling above the bench and against the wall. To the left of the light in the corner of the room was a downwardly and diagonally directed 8-in. diameter fan. To

* Products of the Colonial Sugar Refining Co. Ltd., Australia.

the left and below this fan was a domestic immersion water-heater in an open reservoir (4 in. \times 4 in. by 11 in. in depth), the level of which was maintained constant by a connection to a ball-cock tank outside the warm room. On the floor on all sides of the room were high resistance (black heat) radiators, whose wiring was heat-insulated with "fish fin" beads.

On the control panel were the instruments; two thermostats in series controlled power to the high resistance radiators (one thermostat was set a few degrees above the other, to prevent accidental temperature increases due to stuck contact points). A mercury-switch, human-hair, humidity controller operated the water boiler through a relay. The fluorescent light was controlled by a time

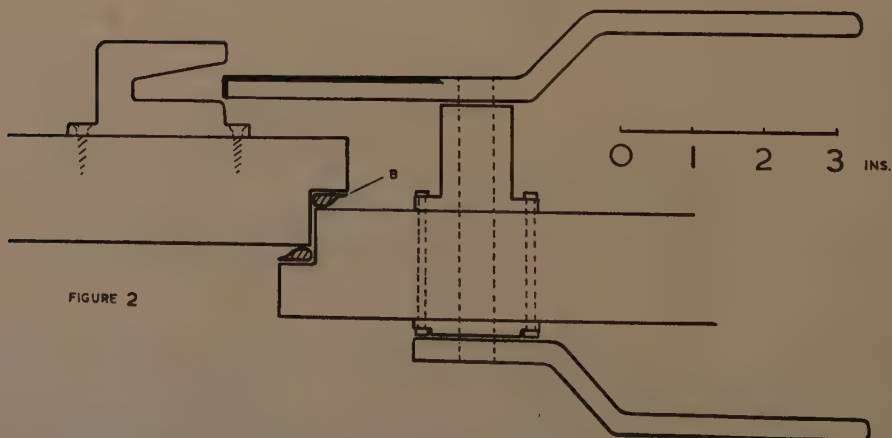
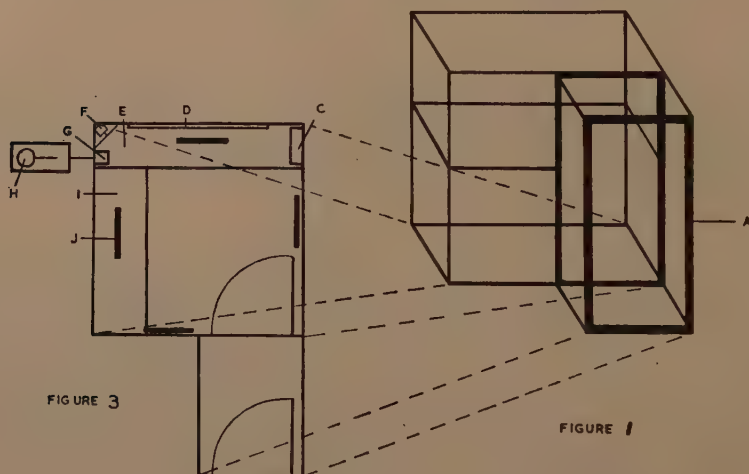


Fig. 1.—Perspective plan of angle steel framework of warm room and insect baffle chamber: A, door jamb. Fig. 2.—Plan of door, jamb, handle and catch (the last rotated through 90° to show slot): B, rubber gasket. Fig. 3.—Floor plan of warm room and insect baffle chamber: C, control panel; D, fluorescent light; E, bench; F, fan; G, immersion heater water reservoir; H, ball-cock water tank; I, shelves; J, high resistance radiators.

switch to give twelve hours of continuous light in every twenty four hours. The fan turned continuously. All this equipment was electrically operated from a series of six switches and sockets on the control panel. Outside the door of the annexe and within it were connected lights to indicate occupancy and to illuminate the annexe for insect recovery.

The total cost of materials and equipment used in the construction of this warm room was A£136.

Operation.

As air was constantly circulated by the fan over the thermostats and humidity controller, any alteration in either temperature or humidity was quickly relayed to them, with a corresponding compensation from the water boiler and/or high resistance radiators. By means of a thermo-hydrograph, the variations in both temperature and humidity have been observed over nine months (winter and summer) and apart from heat-wave conditions and fluctuations due to the opening of doors the temperature was maintained at $78 \pm 1^\circ\text{F}$. with a relative humidity of 75 ± 4 per cent. The "heat-wave conditions" refers to short periods in January, February and March when maximum outdoor temperatures of 104.1° , 94.5° and 84.3°F ., respectively, were recorded. The corresponding indoor maxima were 85.8 , 85.0 and 81.0°F ., respectively. The mean normal illumination within 10 in. \times 10 in. \times 12 in. organdie mosquito cages on the bench and on the shelves ranged from 8.9 lumens per sq. ft. to 0.4 lumens per sq. ft.*

Disadvantages.

Because of the small volume of air inside the warm room, both oxygen depletion and carbon dioxide accumulation were fairly rapid. The opening of doors during entry and exit caused fluctuations in both temperature and humidity of 2°F . and 10 per cent. relative humidity. The lack of refrigeration in summer caused fluctuations during heat-wave conditions, but this could have been overcome by the installation of a cheap cooling system.

Acknowledgements.

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* These measurements were made by the Department of Physics, C.S.I.R.O., and the authors wish to thank Dr. R. G. Giovanelli for this service.

HALTICINAE OF THE SUDAN.

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The Halticine fauna of the Sudan comprises some 39 known species distributed within 19 genera. The largest groups are: *Phyllotreta* (7 species), *Podagrica* (6 species) and *Aphthona* (5 species). The genera *Haltica* and *Epitrix*, though common in other parts of the world, are singularly rare: *Epitrix* has but two species while with *Haltica* there is, so far as can be traced, a single species with only a single specimen from the Sudan. In relation to adjoining territories, the Sudan fauna has much in common with east and central Africa and to a lesser extent with west Africa. In spite of the continuity of the Nile valley, the Ethiopian region boundary demarcates the Sudan species quite sharply from the palaearctic Egyptian. Only four of the 39 species occur in Egypt (El-Zoheiry & Mohamed, 1949). Many of the Sudan species are of minor economic importance, but three can be ranked as major pests. These are the cotton flea-beetles, *Podagrica puncticollis* Weise and *P. pallida* (Jacoby), and the small blue-black *Phyllotreta cheiranthi* Weise on cruciferous vegetables.

Present knowledge on the Sudan HALTICINAE is very limited, particularly with respect to the immature stages. Even the larvae of the cotton flea-beetles (*Podagrica* spp.) have not been described.

This paper is a summary of the distribution and host-plants of the Sudan HALTICINAE, with brief notes on their habits and occurrence, and a key to the species. The information has been compiled mainly with the aid of specimens in the Sudan Government collection at Wad Medani.

LIST OF SPECIES.

In the distribution records, the initial record only, from any one locality, is given. The collector's initials are shown in brackets, full names being as follows:—AAS, A. A. Salam; AD, A. Dafaalla; AG, A. Gaafar; AH, A. Hussein; AM, A. Mustafa; AMM, A. M. Makkawi; APGM, A. P. G. Micheltmore; AS, A. Sillitoe; BBS, B. B. el Shafie; CL, C. Lloyd; DGP, D. G. Pollard; EM, E. McDermid; FGSW, F. G. S. Whitfield; FH, F. Hamid; FJS, F. J. Smart; GY, G. Yahia; HBJ, H. B. Johnston; HF, H. Ferguson; HHK, H. H. King; HO, H. Osman; HWB, H. W. Bedford; JBS, J. B. Stewart; JGM, J. G. Myers; JWC, J. W. Cowland; LEH, L. E. Humphreys; MMI, M. M. Ismail; MN, M. Nasim; MS, M. Steele; PDB, P. D. Broad; RC, R. Cottam; RCMD, R. C. Maxwell-Darling; RJVJ, R. J. V. Joyce; RSA, R. S. Audas; RWW, R. W. Woods; TAK, T. A. Khalifa; VHF, V. H. Fergusson; WEG, W. E. Giffard; WPLC, W. P. L. Cameron; WR, W. Rutledge; WWB, W. W. Bowen.

The "host-plants" include all plants on which a particular beetle species has been taken and are not necessarily food-plants. Where possible, attention has been drawn, in the notes below each species, to known food-plants. Maps showing the present-known distribution of each species in the Sudan follow the pattern used by Lewis (1953). It has not been possible to trace some of the older place-names; these have been included in the text but not on the maps.

***Aphthona bicolor* Jacoby.**

Deriba Lakes (8,000 ft.), 25-29.iv.1932; Dembilbil, (8,300 ft.), 25.v.1932; Karanga, 1932; (MS). These localities are in the Jebel Marra hills in central Darfur. No host-plants are recorded.

***Aphthona fuentei* Rtttr.**

Shambat, 20.ix.1926; Khartoum, 2.ix.1926; Wad Medani, 29.ix.1919; (HWB): Sennar, 16.x.1926; Dilling, 3.x.1926; Singa, 28.xii.1926; Kadugli, 29.xi.1926;



Fig. 1.—Map of the Sudan showing localities mentioned in the text.

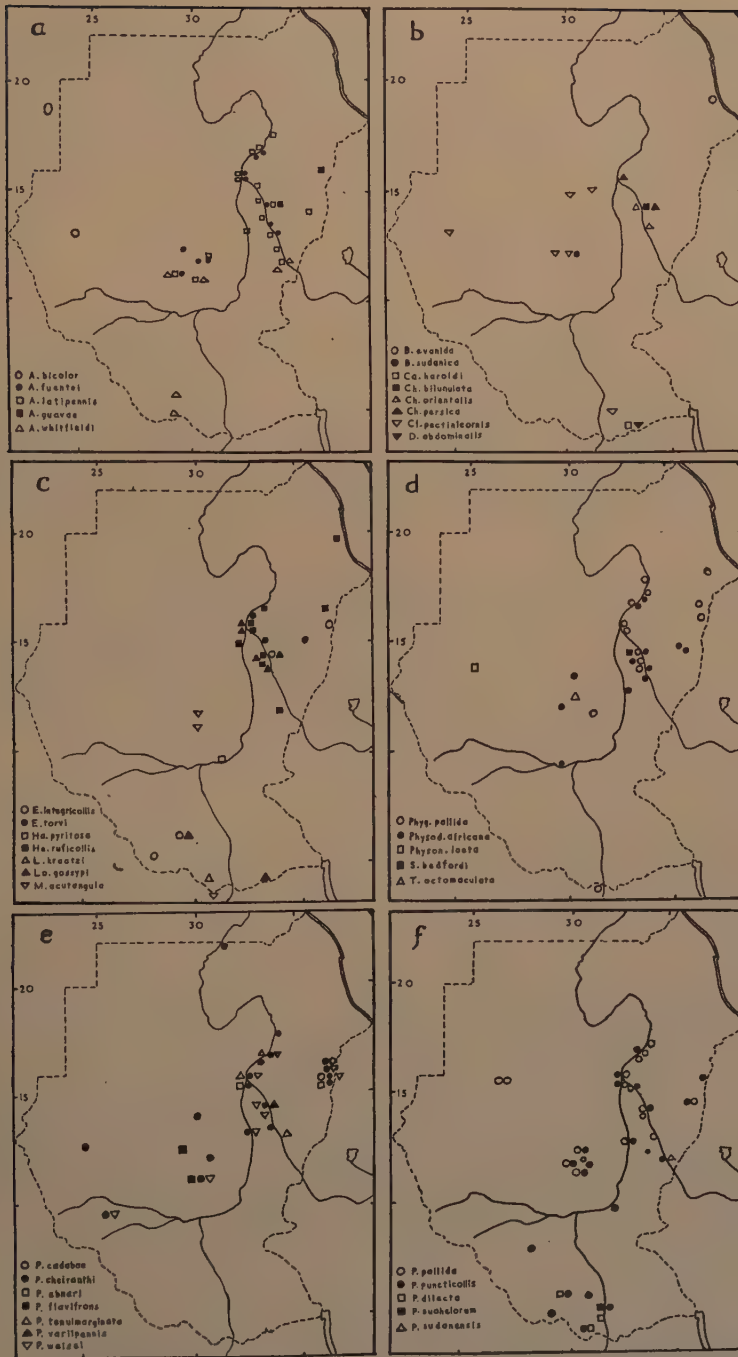


Fig. 2.—Known distribution in the Sudan of: a, *Aphthona*; b, *Blepharida*, *Calothea*, *Chaetocnema*, *Cladocera*, *Decaria*; c, *Epitrix*, *Haltica*, *Hermaeophaga*, *Lactica*, *Longitarsus*, *Myrcina*; d, *Phygasia*, *Physodactyla*, *Physonychis*, *Sphaeroderma*, *Torodera*; e, *Phyllotreta*; f, *Podagricra*.

El Gemmeiza, 2.iii.1927; Rashad, 24.i.1940; (WR): Shendi, ix.1928; Gandeto, 11.x.1928; (AH).

Cotton, *Medicago sativa*, *Cajanus indicus*, *Corchorus* sp., *Heliotropium* sp., *Sorghum caudatum*, *Ipomoea batatas*, *Abutilon pannosum*, *Daedalacanthus* sp., *Solanum melongena*, *Cucumis melo*. Also taken "at light".

A small pale brown flea-beetle confined to the Nile, Blue Nile and Nuba Mountains: also occurs in Egypt and other Mediterranean countries (Heikertinger, 1944). Fairly common between August and October. An occasional minor pest of cotton where it feeds on the foliage. It is commonly present, though in small numbers, on sweet potato (*I. batatas*).

***Aphthona guavae* Bry.**

Aroma, x.1926; (HBJ): Wad Medani, 4.x.1926; (HWB).

Cotton, *Farsetia grandiflora*, *Phyllanthus niruri*, *Phaseolus lathyroides*, *Azadirachta indica*.

Distribution records are meagre for this species; its small size and dark colour have probably enabled it to escape more frequent detection. It feeds on the foliage of all plants listed above with the exception of the tree, *Azadirachta indica*, on which adults can be found resting but not feeding. It has been taken occasionally on cotton, but cannot be regarded as more than a rare visitor.

***Aphthona latipennis* Pic.**

Wad Medani, 18.xi.1919; Zeidab, 12.ii.1919; Shambat, xi.1927; Khartoum, 15.vi.1930; Serdia, 13.ix.1918; (HWB): Gandeto, 20.x.1923; (WEG): Hag Said, 27.iii.1913; (HHK): Singa, 27.ii.1926; Rashad, 24.i.1940; (WR): Kosti, xii.1936; Disa, 24.iii.1927; (JWC): Roseires, 25.ii.1929; (AMM): Talodi, 29.xi.1939; (AM): Kadugli, 13.ii.1931; (FGSW): Gedaref, 20.xi.1948; (RJVJ): Es Sereiha, 3.viii.1941; (MN): Shendi, 13.ii.1925; (AH): Musaad, 7.ii.1952; (DGP): Barakat, 25.vii.1923; (HBJ): Tugarah, xi.1932; (WPLC).

Cotton, *Cajanus indicus*, *Calotropis procera*, *Dolichos lablab*, *Abutilon pannosum*, *Medicago sativa*, *Hibiscus esculentus*, *Aristolochia bracteolata*, *Farsetia grandiflora*, *Heliotropium* sp., *Sorghum vulgare*, *Eclipta alba*, *Nicotiana tabacum*, *Raphanus sativus*, *Phaseolus vulgaris*, *Mangifera indica*, *Pistacia* sp., *Ipomoea* sp. Also taken "at light".

A. latipennis is a conspicuous metallic blue-black beetle with considerable size variation (2.6 to 3.6 mm.) often found in large numbers on various herbs and shrubs. An occasional minor pest on the foliage of some crops such as cotton, *Medicago sativa* and *Cajanus indicus*; it has also been recorded damaging the leaves of mango (*Mangifera indica*) and fruits of the cashew nut (*Pistacia* sp.). Its favourite wild food-plant is *Aristolochia bracteolata*, a small trailing weed widely distributed in the Sudan. The *Ipomoea* sp. recorded above is cultivated as a hedging shrub. In the Wad Medani area, *A. latipennis* occurs on it in large numbers during the dead season† and early rains (May to mid-August). The beetles do not however appear to feed on the shrub, and it is possible that other plants listed above are also used only as resting sites. *A. latipennis* is widely distributed along the Nile and its branches and in the Nuba Mountains: it occurs at all seasons of the year.

***Aphthona whitfieldi* Bry.**

Ibba, 24.v.1937; (JGM): El Kharaba, 7.iv.1933; (WPLC): Talodi, iv.1934; (AM): Meridi, 30.viii.1939; (AG): Kadugli, 13.ii.1931; (FGSW): Roseires, 28.ii.1929; (RSA).

† The annual dead season in the Gezira, during which agricultural crops are not grown and certain vegetables are prohibited, extends between May and July.

Cucumis melo, *Cassia occidentalis*, *Ricinus communis*, *Mangifera indica*, *Vigna sinensis*, *Pistacia* sp., *Nicotiana tabacum*.

Similar in size to *A. latipennis* but red in colour. Has been taken, with the latter species, damaging the leaves of *Mangifera indica* and fruits of *Pistacia* sp. Has also been recorded feeding on the foliage of castor plants (*Ricinus communis*). A southern and Nuba Mountains form occurring as far north as Roseires in the Fung.

***Blepharida eranida* (Baly).**

Two records only, from Erkowit in the Red Sea Hills: xii.1908; and 14.v.1917; (HHK).

***Blepharida sudanica* Bry.**

Recorded only from Delami: 20.vii.1927; and 30.vi.1929; (WR). Two specimens were taken, at light, and were described by Bryant (1945).

***Calotheca haroldi* Baly.**

A single record only, from the Sudan: Imatong Mountains, 4.xii.1933; (MS).

***Chaetocnema batophiloides* Ab.**

Recorded by Abeille de Perrin from the Sudan (1909). No specimens of this species exist in the Sudan Government collection or in the collections of the British Museum (Natural History).

***Chaetocnema bilunulata* Dem.**

One record: Wad Medani, i.1927; (HWB): taken on cotton. Also recorded from Egypt (Heikertinger, 1951).

***Chaetocnema orientalis* (Baud.).**

Wad Medani, 11.i.1927; (HBJ): Sennar, 27.x.1934; (WPLC).

Hordeum vulgare, *Psidium guajava*, *Azadirachta indica*.

Can usually be found, in small numbers, on the foliage of guava trees (*P. guajava*) in Wad Medani.

Chaetocnema persica* Baly.

Khartoum, 15.x.1924; (HBJ): Wad Medani, 13.ix.1925; (AMM).

Cotton, *Cajanus indicus*, *Corchorus olitorius*. Also taken "at light".

***Cladocera pectinicornis* (Ol.).**

Umm Durag (Jebel), 4.ix.1931; Abu Tabar (Jebel); (RCMD): Delami, 26.v.1927; (WR): Kallikitting (4,450 ft.) S. Jebel Marra, 7.vi.1932; (MS): Liria, 7.iv.1932; (HBJ): Ghulfan (Jebel), 11.vi.1934; (AAS).

A large species (10 to 15 mm. in length) confined mainly to the drier and more desert regions of the west. All specimens were taken "at light" with the exception of one on an "abanus" tree.

***Decaria abdominalis* Jacoby.**

Two records only, from the southern Sudan: Karmoto, 29.xii.1933; Imatong Mountains, 11.xii.1933; (MS).

* This species is a synonym of *C. schläflii* (Stierl.).—Ed.

***Epitrix integricollis* Jacoby.**

Wad Medani, 7.iv.1931; (JWC): Meridi, 10.ix.1940; (AG): Yembe, 26.vii.1918; (HWB): Kassala, 26.i.1950; (DGP).

Cotton, *Withania somnifera*.

E. integricollis has a wide distribution but has only seldom been recorded. *W. somnifera* is the only definitely known food-plant: typical shot-holing of the foliage results from feeding.

***Epitrix torvi* Bry.**

Serufab, 24.viii.1928; (HWB): Kadar, 28.x.1941; (MMI): El Boong, 5.ii.1952; (RJVJ).

In all cases the beetles were found feeding on the leaves of egg-plant (*Solanum melongena*).

***Haltica pyritosa* Er.**

Tonga, 10.vii.1911; (HHK): taken "at light on a boat". The only record, and the only species, of *Haltica* found in the Sudan.

***Hermaphysa ruficollis* (Lucas).**

Khor Arba'at, 4.v.1926; El Geteina, 17.iv.1928; (HBJ): Hosh, 14.iii.1923; (WWB): Ingessana Hills, 29.i.1933; Hadaliya, 28.x.1939; Fatisa, 20.ix.1947; (JWC): Wad Medani, 29.ix.1919; (HWB): Khartoum, 9.ix.1917; (RC): Shendi, 1.ix.1928; (AH): Shambat, iv.1909; (HHK).

Cotton, *Chrozophora plicata*, *Corchorus olitorius*, *Heliotropium* sp., *Celastrus* sp., *Sorghum vulgare*, *Dolichos lablab*, *Cajanus indicus*, *Tecoma stans*. Also taken "at light".

A small species varying from pale to dark fulvous in colour. A minor pest on the foliage of cotton, resembling the cotton flea-beetle (*Podagrica* spp.) in habits. Cotton and *Dolichos lablab* are the only known food-plants. Distribution is throughout the central and northern Sudan, extending into Egypt. *H. ruficollis* occurs mainly during the period July to October.

***Lactica kraatzii* Jacoby.**

A single record: Yei—Kagelu, 5.vi.1937; (JGM).

***Longitarsus gossypii* Bry.**

Shambat, 2.x.1926; Khartoum, 26.ix.1926; Wad Medani, 20.ix.1919; (HWB): Hag Abdalla, 30.ix.1942; (JWC): Kumor, 26.viii.1952; (DGP): Meridi, 19.viii.1940; (AG): Ikoto, 14.xii.1933; (MS).

Cotton, *Heliotropium* sp., *Cajanus indicus*, *Balanites aegyptiaca*.

Frequently taken on the foliage of cotton, but not of more than minor importance. Common during the period August to October. *B. aegyptiaca* is probably not a food-plant. *Heliotropium* sp. is a weed food-plant.

***Myrcina acutangula* Har.**

South of Agur, 2.ix.1926; (WR): Jebel Kinderma, 28.vii.1936; (MMI): Khor Kaia (now in Uganda), 30.iv.1911; (HHK). No host-plants known.

***Phygadeuon pallida* Jacoby.**

Zeidab, 3.i.1919; Wad Medani, ix.1923; Barakat, 3.ix.1923; Timerab, 4.iv.1919; (HWB): Gandeto, xi.1925; (WEG): Shambat, viii.1910; Dufle (now in

Uganda), v.1911; (HHK): Hag Abdalla, 29.vii.1929; Mitatib, 18.xi.1932; (WPLC): Makwar, 16.ii.1929; (RCMD): Khartoum, 9.ix.1917; (RC): Hadaliya, 24.ix.1939; (JWC): Abu Gubeiha, 19.v.1937; (AD).

Cotton, *Abutilon pannosum*, *Calotropis procera*, *Medicago sativa*.

The principal food-plant is *Calotropis procera*, a large fleshy shrub with poisonous latex, widely distributed in the Sudan. The beetles feed on leaves and flowers. Occurrence on cotton is rare.

***Phyllotreta cadabae* Bry.**

Hadaliya, 30.x.1939; (JWC): Mekali, 18.ii.1935; (WPLC).

Cadaba rotundifolia.

Both localities are in the eastern Sudan (Gash Delta), where the beetles were found feeding on *Cadaba rotundifolia*. The species was described by Bryant (1941).

***Phyllotreta cheiranthi* Weise.**

Shambat, 2.x.1926; Wad Medani, 8.iii.1922; (HWB): Aroma, x.1926; Kassala, 4.x.1926; (HBJ): Talodi, 23.xii.1936; (AG): Hadaliya, 14.x.1939; Kosti, xii.1936; (JWC): Umm Berembeita, xi.1941; (AMM): Mekali, 18.xi.1935; (WPLC): Bara, 5.ii.1951; (DGP): Shendi, 7.x.1928; Gandeto, 11.x.1928; (AH): Khartoum, 4.x.1913; (AS): Abu Geili, 10.xii.1940; (HO): Wadi Halfa, 17.xi.1938; (MMI): Nyala, xi.1939; Sennar, viii.1934; Ed Damer, 20.x.1938; (?).

Cotton, *Schouwia arabica*, *Brassica campestris*, *B. oleracea*, *Eruca sativa*, *Gynandropsis gynandra*, *Raphanus sativus*, *Phyllanthus niruri*, *Cadaba rotundifolia*, *Corchorus olitorius*, *Medicago sativa*, *Dolichos lablab*.

A small blue-black species widely distributed in the Sudan and known also from Egypt, East Africa and Ceylon (Heikertinger, 1943). It occurs at all times of the year being abundant during the rains (July, August) and winter (November to January). All plants listed above are food-plants; on the crucifers—particularly seedlings—it usually ranks as a major pest. On cotton, *P. cheiranthi* is a rare or minor pest. Little is known of the life-history; the larva is probably soil-dwelling. Heikertinger (1943) considers *P. hargreavesi* Bry. from Uganda synonymous with *P. cheiranthi*.

***Phyllotreta ebneri* Weise.**

Kassala, 4.x.1926; (HBJ): Khartoum, 29.ix.1926; (HWB).

Taken on cotton in both localities. Originally described by Weise from specimens collected at Sennar by Dr. Ebner. The above records are from Heikertinger (1943); no specimens exist in the Sudan Government collection, or in the collections of the British Museum (Natural History). The species is not listed by Bryant (1941).

***Phyllotreta flavifrons* Jacoby.**

Dilling, iii.1931; Talodi, 10.ii.1937; (FGSW).

Hibiscus esculentus, "luweis tree".

A large blue-black form originally described from Somaliland. The above records are from the Nuba Mountains. The "luweis tree" is presumably *Leptadenia heterophylla* (Asclepiadaceae), but the Arabic name is ambiguous.

***Phyllotreta tenuimarginata* Jacoby.**

Shendi, 21.x.1928; Abu Hashim, 13.iii.1929; (RCMD): Shambat, 12.ix.1926; (HWB).

Cotton, *Acacia mellifera*, "grass".

Records meagre, food-plants not known with certainty. *P. bedfordi* Heik.* is a synonym of *P. tenuimarginata*.

Phyllotreta variipennis (Boield.).

A single record: Wad Medani, 5.iii.1922; (HWB): from *Dolichos lablab*. A small form with flavous and black elytra, only once recorded from the Sudan. Not listed by Bryant (1941). Occurs in Egypt (Heikertinger, 1943).

Phyllotreta weisei Jacoby.

Shambat, 27.ix.1928; Wad Medani, iii.1922; (HWB): Aroma, 3.x.1926; Kassala, 4.x.1926; (HBJ): Hamad el Nil, x.1942; Kosti, xii.1936; (JWC): Talodi, 23.xii.1936; (AG): Shendi, 30.ix.1941; (AMM): Abu Geili, 10.xii.1940; (HO).

Cotton, *Medicago sativa*, *Brassica campestris*, *B. oleracea*, *Eruca sativa*, *Raphanus sativus*.

A species with flavous and black elytra, fairly widely distributed in the Sudan. An occasional minor pest of cruciferous crops; on cotton, of very minor importance. *P. bryanti* Heik.* is a synonym of *P. weisei*.

Physodactyla africana Chap.

Wad Medani, 27.vii.1923; Gebelein (W.Nile), vii.1925; (HBJ): Kadugli, 18.ix.1940; (BBS): Shendi, x.1923; Gandeto, 24.x.1923; (WEG): Hag Abdalla, 29.vii.1929; Ghubshan, 27.viii.1932; (WPLC): Nuer, 1923; (VHF): Sobat, 21.vii.1913; (HHK): Sennar, 17.viii.1939; (TAK): El Obeid, ix.1948; (FJS): Gedaref, 19.viii.1946; Ghadambaliya, 25.viii.1947; (RJVJ): Lakoda, 22.vii.1918; (HWB).

Cotton, *Digera arvensis*, *Hibiscus esculentus*, *Calotropis procera*, *Nerium oleander*, *Pennisetum typhoides*, *Sorghum caudatum*, "beans" and "grass".

A large (10 mm. long) uniformly fulvous beetle. Occurs principally during the rains (July to September in central Sudan) when it breeds on *Digera arvensis*. Besides this weed, *Pennisetum typhoides* and "beans" are known food-plants. Occurrence on cotton is rare.

Physonychis laeta Weise.

The only record is from Jebel Kurra (5,600 ft.) in the northern Jebel Marra hills in central Darfur: 4.vii.1932; (MS). Two forms occur, one with blue elytra, the other with green. No host-plants are recorded.

Podagrica dilecta (Dalm.).

Maridi, 6.viii.1937; (BBS): Kagelu, 8.vii.1942; (HF): Juba, 7.ix.1946; (RWW).

Hibiscus cannabinus, *H. esculentus*, *H. sabdariffa*, *Corchorus* sp., *Helianthus tuberosus*.

A species with fulvous thorax and blue elytra, confined to the southern Sudan where it is a minor pest on various species of *Hibiscus*. Common during June to August.

Podagrica pallida (Jacoby).

Khartoum, 17.iii.1913; (HHK): Wad Medani, 29.ix.1919; Dugein, 26.iii.1931; Zeidab, 28.iii.1919; (HWB): Shambat, 1.i.1920; Shendi, 5.ii.1928; (AH): Eliri,

* These two species are both manuscript names.—Ed.

6.vii.1927; Gedaref, 1.i.1928; (JWC): Singa, 28.xii.1926; Delami, 6.vi.1926; Makwar, 17.x.1926; (WR): Tugarah, 17.xi.1932; (WPLC): Kadugli, 12.viii.1937; (AAS): Talodi, 5.xi.1931; (AS): Jebelein, vii.1925; (HBJ): Wadi Madu, 25.vii.1930; Jebel Nasor, 19.vii.1930; (APGM): Khogalab, 7.viii.1932; (GY): Hosh, 6.ii.1923; (WWB): Gandeto, 28.xii.1923; (WEG).

Cotton, *Abutilon pannosum*, *Hibiscus esculentus*, *Grewia villosa*, *Cajanus indicus*, *Dolichos lablab*, *Corchorus olitorius*, *Cienfuegosia digitata*, *Adansonia digitata*, *Phaseolus vulgaris*. Also taken "at light".

A fulvous species, which, with *Podagrira puncticollis* constitutes the "cotton flea-beetle" of the Gezira, Nuba Mountains and Gash Delta. A serious pest, particularly on cotton and *Hibiscus esculentus*, it can also feed on most of the other plants listed above. Distributed across the central region of the Sudan, extending east to Eritrea and west to Darfur, but absent from the south.

Podagrira puncticollis Weise.

Roseires, 12.viii.1935; (CL): Khogalab, 7.viii.1932; Kadugli, 2.iii.1932; (GY): Wad Medani, 29.ix.1919; Khartoum, 3.xii.1931; (HWP): Meridi, 6.viii.1937; Shambat, 10.xii.1931; (BBS): Wau, 16.viii.1946; (RWW): Yambio, 26.ix.1953; (EM): Kassala, 4.x.1926; Jebelein, vii.1935; (HBJ): Mongalla, 1925-6; (LEH): Kologi, 8.x.1937; Talodi, 5.vi.1937; (AG): Ban, 14.x.1928; (WPLC): Delami, 6.vi.1937; Makwar, 16.x.1926; (WR): Kalkooran, xi.1926; (JWC): Sobat, 19.vii.1913; Amade, 8.i.1925; (HHK): Shendi, 15.i.1935; (AH): Malakal, x.1926; (JBS): Kagelu, 16.xii.1942; Gedaref, 10.viii.1947; (?).

Cotton, *Abutilon pannosum*, *Hibiscus esculentus*, *H. sabdariffa*, *H. cannabinus*, *Corchorus olitorius*, *C. fascicularis*, *Sida* sp., *Adansonia digitata*. Also taken "at light".

Very similar in appearance and habits to *P. pallida* and occurring with the latter in the main cotton-growing regions. The "cotton flea-beetle" formerly considered a single species ("*P. puncticollis*") has recently been shown to be a mixture of *P. puncticollis* and *P. pallida* (Pollard, 1955). The distribution of *P. puncticollis* overlaps that of *P. pallida* but extends to the southern Sudan and not so far to the west. Both species occur at all seasons but are most numerous, in the Gezira, at the time of cotton sowing (July and August).

Podagrira spilota (Weise).

The only record is from "East Sudan", a specimen described by Weise in 1919. A distinctive species with red and black elytra.

Podagrira suahelorum (Weise).

A single record: Mongalla, 1925-6; (LEH): from cotton. This species is very close to *P. dilecta* (Dalm.).

Podagrira sudanensis Heik.

Roseires, 8.xi.1926; (WR): from *Abutilon pannosum*. In colour like *P. dilecta*, but of much smaller size.

Sphaeroderma bedfordi Bry.

Wad Medani, 1926; (HWP): Tirangale [near Ikoto], 9.i.1934; (MS). No host-plants recorded.

Toroderma octomaculata Weise.

Delami, 14.vii.1927; (WR). No host-plants recorded.

THE HOST-PLANTS.

The plant species mentioned in the preceding section are tabulated below under families. The common English or Arabic name is given, also the flea-beetles which have been recorded on each plant. Where a particular beetle is not known with certainty to feed on a plant, the beetle species concerned is followed by a query: (?); in all other cases the insect listed is known to feed on the plant. Plants known not to be food-plants are omitted from the list.

Amaranthaceae

CELOSIA sp.—*Hermaphysa ruficollis* (?).

DIGERA ARVENSIS—*Physodactyla africana*.

Anacardiaceae

MANGIFERA INDICA (mango)—*Aphthona latipennis*, *A. whitfieldi*.

PISTACIA sp. (cashew nut)—*Aphthona latipennis*, *A. whitfieldi*.

Aristolochiaceae

ARISTOLOCHIA BRACTEOLATA—*Aphthona latipennis*.

Asclepiadaceae

CALOTROPIS PROCERA—*Aphthona latipennis* (?), *Phygasia pallida*, *Physodactyla africana* (?).

Bombacaceae

ADANSONIA DIGITATA—*Podagrica pallida* (?), *P. puncticollis* (?).

Boraginaceae

HELIOTROPIMUM sp.—*Aphthona fuentei*, *A. latipennis* (?), *Hermaphysa ruficollis* (?), *Longitarsus gossypii*.

Caesalpiniaceae

CASSIA OCCIDENTALIS (senna)—*Aphthona whitfieldi* (?).

Capparidaceae

CADABA ROTUNDIFOLIA—*Phyllotreta cadabae*, *P. cheiranthi*.

GYNANDROPSIS GYNANDRA—*Phyllotreta cheiranthi*.

Compositae

ECLIPTA ALBA—*Aphthona latipennis* (?).

HELIANTHUS TUBEROSUS (Jerusalem artichoke)—*Podagrica dilecta* (?).

Convolvulaceae

IPOMOEA BATATAS (sweet potato)—*Aphthona fuentei*.

Cruciferae

BRASSICA CAMPESTRIS (turnip)—*Phyllotreta cheiranthi*, *P. weisei*.

BRASSICA OLERACEA (cabbage)—*Phyllotreta cheiranthi*, *P. weisei*.

ERUCA SATIVA (rocket cress)—*Phyllotreta cheiranthi*, *P. weisei*.

FARSETIA GRANDIFLORA—*Aphthona guavae*, *A. latipennis* (?).

RAPHANUS SATIVUS (radish)—*Aphthona latipennis* (?), *Phyllotreta cheiranthi*, *P. weisei*.

SCHOEWIA ARABICA—*Phyllotreta cheiranthi*.

Cucurbitaceae

CUCUMIS MELO (sweet melon)—*Aphthona fuentei* (?), *A. whitfieldi* (?).

Euphorbiaceae

CHROZOPHORA PLICATA—*Hermaphysa ruficollis* (?).

PHYLLANTHUS NIRURI—*Aphthona guavae*, *Phyllotreta cheiranthi*.

RICINUS COMMUNIS (castor)—*Aphthona whitfieldi*.

Gramineae

- HORDEUM VULGARE (barley)—*Chaetocnema orientalis* (?).
 PENNISETUM TYPHOIDES—*Physodactyla africana*.
 SORGHUM CAUDATUM—*Aphthona fuentei* (?), *Physodactyla africana* (?).
 SORGHUM VULGARE—*Aphthona latipennis* (?), *Hermacophaga ruficollis* (?).

Leguminosae

- CAJANUS INDICUS—*Aphthona fuentei*, *A. latipennis*, *Chaetocnema persica** (?),
Hermacophaga ruficollis (?), *Longitarsus gossypii* (?), *Podagrica pallida* (?).
 DOLICHOS LABLAB—*Aphthona latipennis*, *Hermacophaga ruficollis*, *Phyllotreta*
cheiranthi, *P. variipennis* (?), *Podagrica pallida*.
 MEDICAGO SATIVA—*Aphthona fuentei*, *A. latipennis*, *Phygasia pallida* (?), *Phyllo-*
treta cheiranthi, *P. weisei* (?).
 PHASEOLUS LATHYROIDES—*Aphthona guavae*.
 PHASEOLUS VULGARIS—*Aphthona latipennis* (?), *Podagrica pallida*.
 VIGNA SINENSIS—*Aphthona whitfieldi*.

Malvaceae

- ABUTILON PANNOSUM—*Aphthona fuentei* (?), *A. latipennis* (?), *Phygasia pallida*,
Podagrica pallida, *P. puncticollis*, *P. sudanensis*.
 CIENFUEGOSIA DIGITATA—*Podagrica pallida*.
 GOSSYPIUM BARBADENSE, G. HIRSUTUM (cotton)—*Aphthona fuentei*, *A. guavae*, *A.*
latipennis, *Chaetocnema bilunulata* (?), *C. persica** (?), *Epitrix integricollis*
 (?), *Hermacophaga ruficollis*, *Longitarsus gossypii*, *Phygasia pallida*, *Phyllo-*
treta cheiranthi, *P. ebneri* (?), *P. tenuimarginata* (?), *P. weisei*, *Physo-*
dactyla africana, *Podagrica pallida*, *P. puncticollis*, *P. suahelorum*.
 HIBISCUS CANNABINUS—*Podagrica dilecta*, *P. puncticollis*.
 HIBISCUS ESCULENTUS—*Aphthona latipennis* (?), *Phyllotreta flavifrons* (?),
Physodactyla africana (?), *Podagrica dilecta*, *P. pallida*, *P. puncticollis*.
 HIBISCUS SABDARIFFA—*Podagrica dilecta*, *P. puncticollis*.
 SIDA sp.—*Podagrica puncticollis*.

Mimosaceae

- ACACIA MELLIFERA—*Phyllotreta tenuimarginata* (?).

Myrtaceae

- PSIDIUM GUAJAVA (guava)—*Chaetocnema orientalis* (?).

Solanaceae

- NICOTIANA TABACUM (tobacco)—*Aphthona latipennis* (?), *A. whitfieldi* (?).
 SOLANUM MELONGENA (egg-plant)—*Aphthona fuentei* (?), *Epitrix torvi*.
 WITHANIA SOMNIFERA—*Epitrix integricollis*.

Tiliaceae

- CORCHORUS FASCICULARIS—*Podagrica puncticollis*.
 CORCHORUS OLITORIUS—*Chaetocnema persica** (?), *Hermacophaga ruficollis* (?),
Phyllotreta cheiranthi, *Podagrica pallida*, *P. puncticollis*.
 CORCHORUS sp.—*Aphthona fuentei*, *Podagrica dilecta*.
 GREWIA VILLOSA—*Podagrica pallida*.

Key to the Sudan HALTICINAE.

- | | | |
|---|--------------------------------------------------------------------------|------------------------------------|
| 1 | (2) : Antennae pectinate, large species (10 mm.) with black markings | |
| | | <i>Cladocera pectinicornis</i> Ol. |
| 2 | (1) : Antennae filiform | 3 |
| 3 | (24) : Elytra bicolorous (at least with blackish suture or margin) | 4 |

* Cf. p. 77.

4 (5) :	Elytra red and black	<i>Podagrica spilota</i> (Weise)	6
5 (4) :	Elytra flavous, fulvous or testaceous, and black		7
6 (13) :	Elytra punctate-striate		9
7 (8) :	Punctuation geminate	<i>Blepharida sudanica</i> Bry.	
8 (7) :	Punctures in single rows		11
9 (10) :	Prothorax unicolorous greenish-black	<i>Chaetocnema orientalis</i> (Baud.)	
10 (9) :	Basic colour of prothorax flavous or fulvous		15
11 (12) :	Prothoracic basal sulci present, elytra with black markings, length 5 mm.	<i>Calotheca haroldi</i> Baly	
12 (11) :	Basal sulci absent, elytral markings sparse, length 8 mm.	<i>Blepharida evanida</i> (Baly)	
13 (6) :	Elytra punctate		17
14 (19) :	Prothorax blackish		20
15 (16) :	Prothorax metallic black; yellow maculae of elytra narrowed at middle	<i>Phyllotreta ebneri</i> Weise	
16 (15) :	Prothorax faint greenish-black; maculae of elytra narrowed slightly at middle		22
17 (18) :	Shoulder strongly developed	<i>Phyllotreta weisei</i> Jacoby	
18 (17) :	Shoulder weakly developed	<i>Phyllotreta variipennis</i> (Boield.)	
19 (14) :	Prothorax flavous, fulvous or testaceous		25
20 (21) :	Four black maculae on each elytron, size 4-5 mm.	<i>Torodera octomaculata</i> Weise	
21 (20) :	Suture of elytra blackish, size 2 mm. or less		28
22 (23) :	First hind tarsal segment as long as half the tibia	<i>Longitarsus gossypii</i> Bry.	
23 (22) :	First hind tarsal segment shorter than half the tibia	<i>Phyllotreta tenuimarginata</i> Jacoby	
24 (3) :	Elytra unicolorous		30
25 (36) :	Elytra and prothorax of different colours		32
26 (27) :	Prothorax black, elytra fulvous	<i>Lactica kraatzii</i> Jacoby	
27 (26) :	Prothorax fulvous; elytra black, blue-black, blue or green		34
28 (29) :	Prothoracic basal sulci nearly half the length of prothorax; elytra blue-black, semi-punctate-striate	<i>Podagrica sudanensis</i> Heik.	
29 (28) :	Basal sulci very weak or absent		36
30 (31) :	Elytra black, small species (2 mm.)	<i>Phyllotreta cadabae</i> Bry.	
31 (30) :	Elytra blue-black, blue or green		38
32 (33) :	Anterior prothoracic sulci present	<i>Podagrica dilecta</i> (Dalm.), <i>P. suahelorum</i> (Weise)	
33 (32) :	Anterior sulci absent		40
34 (35) :	Prothoracic margin flattened with anterior angles produced, last hind tarsal segment swollen, elytra blue or green	<i>Physonychis laeta</i> Weise	
35 (34) :	Prothoracic margin small without prominent angles, last hind tarsal segment not swollen, elytra blue-black	<i>Aphthona bicolor</i> Jacoby	
36 (25) :	Elytra and thorax concolorous		42
37 (56) :	Upper surface blackish		44
38 (43) :	Elytra punctate-striate		46
39 (40) :	Prothoracic basal sulci present	<i>Chaetocnema persica</i> Baly *	
40 (39) :	Basal sulci absent		48
41 (42) :	Legs pale fulvous	<i>Epitrix integricollis</i> Jacoby	
42 (41) :	Legs dark fulvous	<i>Epitrix torvi</i> Bry.	

* Cf. p. 77.

43 (38) :	Elytra punctate	44
44 (53) :	Antennae entirely black, hind legs unicolorous	45
45 (48) :	A transverse depression present between disc and hind margin of prothorax	46
46 (47) :	Dull black	<i>Myrcina acutangula</i> Har.
47 (46) :	Metallic green-black	<i>Haltica pyritosa</i> Er.
48 (45) :	Transverse depression absent between disc and hind margin of prothorax	49
49 (50) :	Small species (2 mm.), blue-black	<i>Phyllotreta cheiranthi</i> Weise
50 (49) :	Larger species (over 3.5 mm.)	51
51 (52) :	Blue- or violet-black, prothorax wider than head	<i>Aphthona latipennis</i> Pic
52 (51) :	Black, prothorax scarcely wider than head	<i>Decaria abdominalis</i> Jacoby
53 (44) :	Antennae black and pale fulvous, hind femora darker than tibia	54
54 (55) :	Frons flat, black	<i>Aphthona guavae</i> Bry.
55 (54) :	Frons keeled, flavous	<i>Phyllotreta flavifrons</i> Jacoby
56 (37) :	Upper surface fulvous, testaceous or fulgid	57
57 (60) :	Upper surface fulgid	58
58 (59) :	Hind femora black; shape ovoid	<i>Aphthona whitfieldi</i> Bry.
59 (58) :	Hind femora fulgid; shape oval	<i>Sphaeroderma bedfordi</i> Bry.
60 (57) :	Upper surface fulvous or testaceous	61
61 (64) :	A transverse depression present between disc and hind margin of prothorax	62
62 (63) :	Pale to dark fulvous or testaceous, size 2 mm.	<i>Hermaphysa ruficollis</i> (Lucas)
63 (62) :	Very pale fulvous, size 3-5 mm.	<i>Phygasia pallida</i> Jacoby
64 (61) :	Transverse depression absent between disc and hind margin of prothorax	65
65 (68) :	Prothoracic basal sulci present	66
66 (67) :	Aedeagus with rounded apex	<i>Podagrica pallida</i> (Jacoby)
67 (66) :	Aedeagus with notched apex	<i>Podagrica puncticollis</i> Weise
68 (65) :	Prothoracic basal sulci absent	69
69 (70) :	Small (2 mm.), pale fulvous	<i>Aphthona fuentei</i> Rtrr.
70 (69) :	Large (7-12 mm.), dark fuscous or testaceous	<i>Physodactyla africana</i> Chap.

Two species, of which specimens were not available (*Chaetocnema batophiloides* and *C. bilunulata*), have not been included in this key. Two species of *Podagrica* (*P. dilecta* and *P. suahelorum*) have not been separated from each other: all the blue-elytra forms of *Podagrica* are in urgent need of revision, and until this is complete it is considered inadvisable to give characters for separating these two species. *P. sudanensis* is a very distinctive form, and has therefore been separated in the key.

ECONOMIC IMPORTANCE.

Of the 39 known species of Sudan HALTICINAE, 21 have been recorded from cultivated plants. The majority of these are minor or occasional pests and only three species can be considered serious. Two of these, *Podagrica pallida* and *P. puncticollis* on cotton, are of major economic importance, while the third, *Phyllotreta cheiranthi*, is a serious pest of crucifers. However, the relatively small areas under cultivation to cruciferous vegetables limit the economic importance of this latter insect.

Considering the large scale of cotton cultivation, it is not surprising to find

that insect records from this plant are more complete than in the case of other crops. Twelve species of HALTICINAE are known to feed on cotton† while a further four are suspected of doing so. Hargreaves (1948) lists only five species from the Sudan. In the case of two of these (*Phyllotreta tenuimarginata* and *Podagrica dilecta*) it has not been possible to trace any definite record of feeding on cotton, though it is very probable that they do so.

One species (*Podagrica uniformis* (Jacoby)) listed by Hargreaves (1948) does not occur in the Sudan, but is confined to cotton in west and west-central Africa. Furthermore, the cotton flea-beetle in the Sudan is, at least in the main cotton-growing areas, a mixture of two species, *Podagrica puncticollis* and *P. pallida* (Pollard, 1955).

Species of the genus *Podagrica* in the Sudan, as in other parts of the world, are common on the Malvales. In the Malvaceae, plants attacked include several species of *Hibiscus*, such as *H. esculentus* and *H. cannabinus*, while in the Tiliaceae, vegetable and fibre plants of *Corchorus* are damaged.

On Cruciferae, *Phyllotreta cheiranthi* is frequently of importance during the winter months, especially on radish and cabbage. In common with other flea-beetles, attack usually takes place during the seedling stage when the entire crop may be destroyed. Damage is in all cases caused by the adults shot-holing the leaves.

The larvae of *Podagrica* spp. are subterranean, living on the rootlets of the food-plants but the damage is, so far as is known, slight. Larvae of *Phyllotreta cheiranthi* are presumably also subterranean, but the life-history of this species has not yet been investigated.

Control of flea-beetles in the Sudan has, up to the present, been achieved by spraying or dusting with DDT or BHC. Further details of this aspect will be given in later publications.

Summary.

The distribution of the Sudan HALTICINAE is given, together with brief notes on the food-plants and habits where known, and a key to the species.

Some 39 species, within 19 genera, are known to occur. Many are of minor economic importance, but three can be ranked as major pests. These are the two cotton flea-beetles, *Podagrica puncticollis* Weise and *P. pallida* (Jacoby), and *Phyllotreta cheiranthi* Weise on cruciferous vegetables.

References.

- ABEILLE DE PERRIN, E. (1909). Coléoptères d'Algérie jugés nouveaux. 2. *Chaetocnema batophiloides*, n.sp.—Bull. Soc. ent. Fr., **1909**, p. 180.
- BRYANT, G. E. (1941). On the African species of *Phyllotreta* (Col., Halticinae).—Bull. ent. Res., **32**, pp. 145–152.
- BRYANT, G. E. (1942). New species of *Podagrica* (Halticinae, Coleoptera) from Africa.—Bull. ent. Res., **33**, pp. 229–234.
- BRYANT, G. E. (1945). New species of *Blepharida* from Africa (Halticinae, Col.).—Ann. Mag. nat. Hist., (11) **12**, pp. 129–137.
- EL-ZOHEIRY, M. S. & MOHAMED, N. (1949). List of Egyptian insects in the collection of the Entomological Section.—87 pp. Ent. Sect., Minist. Agric., Egypt.

† It is not possible to differentiate between Egyptian and American cottons (*Gossypium barbadense* and *G. hirsutum* respectively) in this paper. Most insect records refer simply to "cotton" and it is generally impossible to determine which species of cotton is concerned.

- HARGREAVES, H. (1948). List of recorded cotton insects of the world.—50 pp. London, Commonw. Inst. Ent.
- HEIKERTINGER, F. (1943). Die *Phyllotreta*-Arten des äthiopischen Faunengebietes (Coleoptera: Chrysomelidae).—Arb. morph. taxon. Ent., **10**, pp. 33–56.
- HEIKERTINGER, F. (1944). Bestimmungstabellen europäischer Käfer (10.Stück) . . . Bestimmungstabelle der paläarktischen *Aphthona*-Arten.—Koleopt. Rdsch., **30**, pp. 37–124.
- HEIKERTINGER, F. (1951). Bestimmungstabellen europäischer Käfer (12.Stück) . . . Bestimmungstabellen der paläarktischen Arten der Gattungen *Podagrica* Foudr., *Mantura* Steph. und *Chaetocnema* Steph.—Koleopt. Rdsch., **32**, pp. 1–84.
- LEWIS, D. J. (1953). The Tabanidae of the Anglo-Egyptian Sudan.—Bull. ent. Res., **44**, pp. 175–216.
- POLLARD, D. G. (1955). The identity of the Cotton Flea Beetle of the Sudan.—Ann. Mag. nat. Hist., (12) **8**, pp. 713–717.
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STUDIES ON THE RESPONSES OF THE FEMALE *Aedes* MOSQUITO.PART VII.—THE EFFECT OF SKIN TEMPERATURE, HUE
AND MOISTURE ON THE ATTRACTIVENESS
OF THE HUMAN HAND.

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P.L.

(PLATE I.)

Previous communications in this series have reported that surface warmth, darkness, and moisture are attractive factors for *Aedes* mosquitos, the demonstrations having been made on inanimate objects. The attractiveness of warmth independent of moisture was demonstrated on plastic balls for *Aedes aegypti* (L.) in the laboratory (Peterson & Brown, 1951) and on clothed robots for Canadian species of *Aedes* in the open air (Brown, 1951). The superior attractiveness of dark-hued or black surfaces was similarly demonstrated in the laboratory (Brown, Sarkaria & Thompson, 1951) and with robots in the field; it was later shown that the attractiveness of a surface was inversely proportional to its reflectivity in the range of wavelength between 475 and 625 millimicrons (Brown, 1954). The attractiveness of moisture was demonstrated with moist air emitted from an olfactometer in the laboratory, and with moistened clothing on robots in the field. The purpose of the experiments to be reported in this paper is to investigate the effect of these three factors on the attractiveness of the skin of the human hand.

Material and Methods.

The species employed was the yellow fever mosquito, *Aedes aegypti*, which was reared according to the methods described by Brown, Sarkaria & Thompson (1951). Tests were conducted using the adult females in a large cage of 360 cu. ft. capacity. Two ports were cut in the side of the cage, 16 in. apart and 4.5 ft. from the floor, and to them were attached reversible sleeves of white broadcloth, 18 in. long, each with an elastic band to fit round the wrist.

The human hand was the test object, and the hands of two different individuals were compared for their attractiveness. They were simultaneously thrust into the cage and held there, fingers outstretched and appressed, for 15 sec. while an observer counted the number of mosquito landings on each. They were removed, the hands interchanged between the sleeves, and again introduced for 15 sec.; a total of 18 such counts constituted a test. The results of each test were statistically analysed by applying Student's *t* test to the variance of the counts.

Skin temperatures were measured by pressing copper-constantan thermocouples into the back of the hand; these were connected through a switch to a pointer-type galvanometer (G.-M. Laboratories) sensitive to 0.1 microamp. per mm. Skin hues were selected visually and confirmed by photographing from 10 ft. under a floodlight with Ortho-X sheet film and printing on to Kodak F-4 paper. Skin humidity was measured as the mg. of moisture transpired in 30 min. when the hand of a sitting subject was enclosed in a 4-g. polythene bag (Canadian

Industries Ltd.) measuring $5 \times 3 \times 14$ in., and secured with an elastic band at the wrist.

The Effect of Skin Temperature.

The hands of 150 males of the Caucasian race, 18 to 20 years old, were tested by thermocouple, and the skin temperature while the subjects rested at room temperature was found to range between 28.3°C . and 33.2°C . From these subjects, pairs were chosen whose skin pigmentation was approximately similar, one being warm-skinned and the other cool-skinned. The attractiveness of their hands was compared in the large cage containing adult mosquitos, at air temperatures between 75 and 85°F ., and relative humidities between 60 and 75 per cent. The results of seven such comparisons are shown in Table I.

TABLE I.

Seven comparisons of hands of warm-skinned with those of cool-skinned Caucasians.

Surface temperature ($^{\circ}\text{C}$.)			Landing rate		Index of attraction (Warm)	Student's t
Warm	Cool	Diff.	Warm	Cool		
32.8	29.5	3.3	160	127	56	2.06
33.2	30.1	3.1	79	54	59	2.68
31.3	28.5	2.8	207	159	57	2.67
31.1	28.6	2.5	75	43	64	2.49
30.6	28.3	2.3	235	196	54	1.60
32.3	30.3	2.0	495	365	58	4.21
31.2	29.6	1.6	171	154	53	1.43
Entire test :			1422	1098	56.5	5.84

In each of the seven tests, between 53 and 64 per cent. of the total landings were on the warmer hand, and the index of attraction computed on this basis from the total counts of all seven tests was 56.5 per cent. When the variance was analysed it was found that four out of the seven individual tests showed a significant difference at the 5 per cent. level ($t > 2.11$), and that the t value of 5.84 for the entire set of counts indicated a highly significant difference. It is interesting to note that the least differences in attractiveness were obtained in the pairs that differed least in skin temperature; however the positive and the correlation coefficient of 0.35 between the indices of attractiveness and the differences in temperature was only half as great as that required for significance at the 5 per cent. level.

The superior attractiveness of the warmer hand was then demonstrated on single individuals by cooling their other hand in ice-water. It was enclosed in a rubber glove and kept in ice-water until the pain demanded its removal, and then immersed again until the skin temperature had fallen to approximately 22°C .; the hand was then dried and compared for attractiveness with the normal hand. Thirty successive 15-sec. exposures were made as the cooled hand

returned to a normal temperature, thermocouple readings being taken between each exposure; fifteen min. later the other hand was cooled and the exposures repeated. The results for the 30 exposures were averaged in ten groups of three each. This experiment was repeated five times, using different subjects; the totals obtained in the five experiments for each temperature class of the cooled hand are shown in Table II. The figures clearly show that a cooled hand is

TABLE II.

Comparison of cooled hands with normal hands of Caucasians.

Temperature range of cooled hands (°C.)	Landing rate		Index of attraction for cooled hands
	Cooled	Normal	
22.0 – 22.9*	13	63	17
24.0 – 24.9	45	179	20
25.0 – 25.9	16	60	21
26.0 – 26.9	83	253	25
27.0 – 27.9	55	136	29
28.0 – 28.9	157	345	31
29.0 – 29.9	150	334	31
30.0 – 30.9	158	344	32
31.0 – 31.9	216	589	27
32.0 – 32.9	191	315	38
33.0 – 33.9†	163	365	32

* No skin temperatures fell within the range 23.0–23.9°C.

† Temperature range of normal hands 30.9–34.0°C.

considerably less attractive than a normal one, that its relative attractiveness increases as it returns to a normal temperature, but at this point it has recovered slightly less than half of the attractiveness of the normal hand.

This type of experiment was repeated by warming one of the hands in a bath of hot water, using the rubber glove, to a skin temperature of approximately 37°C. It was compared for attractiveness with the normal hand by the same methods as previously described, and nine separate experiments were performed. The results, shown in Table III, fail to demonstrate any superior attractiveness for the warmed hand, which tended in fact to attract fewer mosquitos. The differences of the heated hand between 33 and 35°C., with an index of attraction of 46 per cent., were found to be not significant from the normal at the 5 per cent. probability level.

It was observed that after cooling or warming, the hand became flushed. This red colour persisted even after the hand had returned to its normal temperature. An experiment was therefore devised to determine whether this redness had any effect on the landing rate of mosquitos. A hand was heated in a hot-water bath, dried thoroughly, and on returning to its normal skin temperature was compared to a normal hand. From four experiments, each with 18 counts

of 15 seconds' duration, the total landing rate on the red hand was 533 as against 509 for the normal hand. It is therefore clear that skin redness, independent of temperature differences, has no effect on the attractiveness of the hand, and thus does not introduce error into the experiments. The swelling which occurred when the hand was heated was determined, by water displacement, to be less than 5 per cent. of the original volume, and thus the increase in linear dimensions could scarcely be an interfering factor in the experiments.

TABLE III.

Comparison of warmed hands with normal hands of Caucasians.

Temperature range of warmed hands (°C.)	Landing rate		Index of attraction for warmed hands
	Warmed	Normal	
36.9 - 36.0	58	112	34
35.9 - 35.0	80	129	38
34.9 - 34.0	313	370	46
33.9 - 33.0	424	490	46
32.9 - 32.0*	84	128	40

* Temperature range of normal hands 33.7-31.5°C.

The Effect of Skin Hue.

Nine comparisons were made of the attractiveness of darkly pigmented men of the Caucasian race as compared with light-skinned Caucasians having approximately the same skin temperature (Pl. I, fig. 1). The results are shown

TABLE IV.

Nine comparisons of hands of dark-skinned with those of light-skinned Caucasians.

Landing rate		Index of attraction (%) Dark	Student's t
Dark	Light		
164	110	59	5.00
593	460	57	3.68
214	164	57	2.42
204	160	56	2.83
178	141	56	2.46
449	368	55	1.79
280	228	55	1.65
189	193	49	0.20
146	157	48	0.62
2417	1981	55.0	5.32

in Table IV. Between 48 and 59 per cent. of the total landings were on the darker hand, and the index of attraction for the total counts of all nine tests was 55.0 per cent. When statistically analysed, five out of the nine tests showed a significant difference at the 5 per cent. level, and the *t* value of 5.32 for the entire set of counts indicated a highly significant difference.

Nine comparisons were made between Negroes and light-skinned Caucasians having approximately the same skin temperature. The results are shown in Table V. Between 54 and 69 per cent. of the total landings were on the hand of the Negro, and the index of attraction for all the counts was 61.5 per cent. The *t* values show that eight of the nine individual tests showed significant

TABLE V.

Twenty six comparisons between hands of Negroes, Orientals and light-skinned Caucasians.

Landing rate		Index of attraction (%)	Student's t
Dark	Light		
Negroes vs. Caucasians			
358	161	69	8.38
319	159	67	8.07
251	145	63	3.35
405	245	62	5.26
446	288	61	4.00
289	190	60	3.14
215	145	60	2.84
164	131	57	2.26
287	246	54	2.10
2734	1710	61.5	11.75
Negroes vs. Orientals			
430	279	61	5.08
356	233	60	3.76
168	118	59	4.34
405	296	58	4.46
207	152	58	4.07
466	364	56	4.54
400	331	55	2.95
366	309	54	3.64
2798	2082	57.3	9.50
Orientals vs. Caucasians			
127	79	62	4.30
191	142	57	2.64
132	101	57	1.30
125	95	57	1.69
298	233	56	4.51
275	219	56	2.41
341	278	55	4.14
146	125	54	1.38
107	95	52	0.48
1742	1367	56.0	6.81

difference at the 5 per cent. level, six out of the nine were significant at the 1 per cent. level (where $t_{17}=2.90$) and the t value of 11.75 for the entire set of counts is very highly significant.

The hands of Negroes were then compared with hands of similar temperature of Orientals (Pl. I, fig. 2). Between 54 and 62 per cent. of the total landings were on the Negro hand, the index of attraction for the entire series being 57.3 per cent. All of the eight tests showed significant difference at the 1 per cent. level, and the t value for the entire set of counts was 9.50.

Nine comparisons were made between Orientals and light-skinned Caucasians matched for skin temperature (Pl. I, fig. 3). The results in Table V show that between 52 and 65 per cent. of the total landings occurred on the hand of the Oriental, and the index of attraction for all the counts was 56.0 per cent. However, only three of the nine experiments showed a significant difference at the 1 per cent. level, although the t value of 6.81 for all the figures has a high level of significance.

The Combined Effect of Skin Hue and Temperature.

Nine comparisons were made between warm-skinned, dark-complexioned hands and cool, light-hued hands. The results are shown in Table VI. The warm, dark skins attracted between 52 and 61 per cent. of the total mosquito landings, and four out of the nine tests showed significant difference at the 1 per cent. level. The t value for the entire series was 6.29, indicating a very significant

TABLE VI.

Comparisons of warm, dark with cool, light, and of warm, light with cool, dark, hands of Caucasians.

Landing rate		Index of attraction (%)	Student's t
Warm, dark	Cool, light	Warm, dark	
197	124	61	6.77
253	177	59	4.46
101	71	59	2.07
185	134	58	3.38
98	73	57	2.25
123	95	56	2.21
196	170	54	1.61
293	266	52	0.88
247	231	52	0.60
1693	1341	55.7	6.29
Warm, light	Cool, dark	Warm, light	
219	140	61	3.96
107	76	58	2.41
167	125	57	2.79
144	111	56	3.21
73	62	54	0.74
197	177	53	0.92
115	100	53	0.81
266	288	48	0.92
158	178	47	0.92
1446	1257	53.4	4.91

difference. However, the overall index of attraction, which was 55.7 per cent. for the warmer, darker hand, as well as the *t* value, was no higher than when warm-skinned hands were compared with cool-skinned hands of similar pigmentation (index of attraction 56.5, *t* value 5.84).

Nine comparisons were then made between warm-skinned, light-complexioned hands and cool, dark-hued hands. The results are also shown in Table VI. The warm, light hands attracted between 47 and 61 per cent. of the landings. The index of attraction for the series was 53.4 per cent., and the *t* value for the 161 degrees of freedom involved was 4.91, significant at the 0.1 per cent. level.

The Effect of Skin Humidity.

Twenty five Caucasian males, 18 to 20 years old, were tested for the output of humidity from the hand. The lengths of their hands, measured from the pisiform bone of the wrist to the tip of the middle finger, ranged from 202 to 236 mm. The moisture output of one of their hands, when determined for a 30-minute period at room temperature in the winter, ranged from 198 to 722 mg. and averaged at 441 mg., with a coefficient of variation of 39.4 per cent. Two groups of seven individuals were selected from either extreme of output, and were retested two months later; the correlation coefficient between the two sets of moisture determinations was 0.59. The individuals in the high-output group

TABLE VII.

Comparison of hands of dry-skinned with those of moist-skinned Caucasians. Indices of attraction as per cent. (I.A.) for the dry hand in relation to its difference in moisture output in mg. (D.M.) of the moist hand.

Moisture output			Landing rate			<i>t</i>
Moist hand	Dry hand	D.M.	Dry hand	Moist hand	I.A.	
810	264	546	31	10	75	3.36
810	264	546	50	29	63	3.20
810	295	515	35	10	78	4.65
810	295	515	98	50	66	2.86
810	314	496	108	57	65	4.19
810	338	472	98	53	65	2.99
810	338	472	214	122	64	4.10
556	198	358	160	111	59	1.84
538	295	343	41	26	61	1.63
512	198	314	86	78	52	0.32
556	264	292	36	27	57	0.94
556	295	261	39	17	69	2.68
556	309	247	53	49	52	0.40
443	198	245	30	26	54	0.48
556	314	242	49	32	61	1.91
538	314	224	46	38	55	0.76
556	338	218	29	24	55	0.49
512	309	203	50	29	63	2.81
538	338	200	20	14	59	0.81
512	338	174	42	26	62	1.43
453	295	158	32	28	53	0.67
453	309	144	51	50	51	0.11
481	338	143	53	34	61	2.76
481	338	108	44	44	50	0.00
443	338	105	38	29	57	0.98
453	373	80	36	45	45	0.86
		292			59.7	7.59

transpired between 443 and 810 mg. each from the average of the two determinations; those in the low-output group transpired between 198 and 338 mg.

Members from each group were compared in pairs, a total of 26 comparisons for attractiveness being made. In all cases, the skin temperature of the one individual did not differ by more than 0.5°C . from the other. The mosquito population was lower than in the previous experiments, the total landing rates per comparison ranging between 53 and 336. Relative humidities during tests were between 30 and 65 per cent., and the temperatures between 78 and 90°F . The results are shown in Table VII, in which the difference in moisture output between the pair tested, the index of attraction, and the t value are tabulated.

With one exception the hand with the lower moisture output was always the more attractive of the pair, receiving between 45 and 78 per cent. of the total landings. The figures from the entire series give an index of attraction for the drier hands of 59.7 per cent. Statistical analysis of all the 468 counts yielded a t value of 7.59, indicating that the difference in favour of the drier hands was extremely significant. However, since the landing rates were low, statistical significance for differences in individual tests were obtained only when indices of attraction were high.

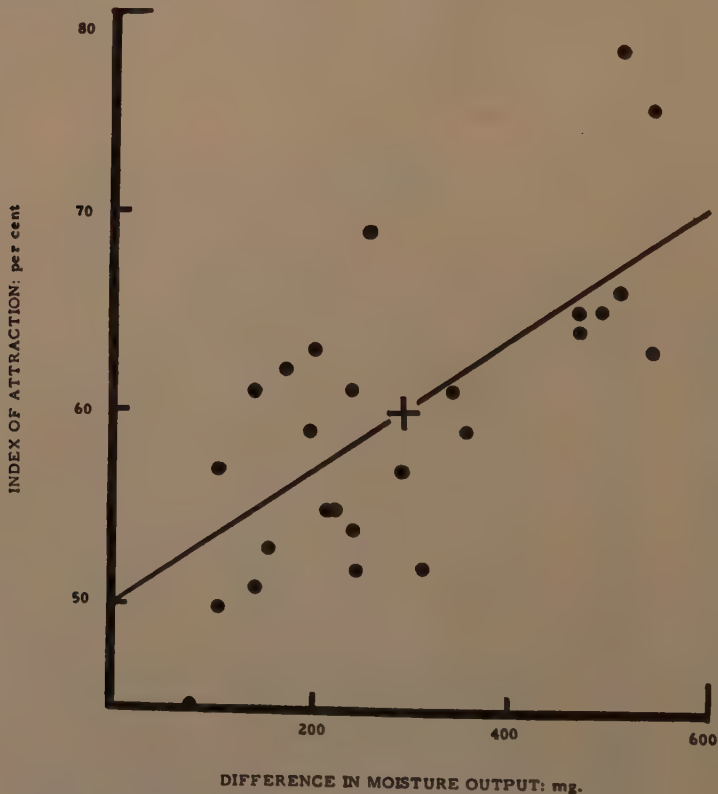


Fig. 1.—Relation between index of attraction of drier hand and the differential in moisture output from the moister hand.

It will be noted that the higher indices of attraction were obtained where the difference in moisture output between each member of the pair was greatest. The relation between the two values are plotted in fig. 1, and the points are well distributed around a line drawn from the origin of 50 per cent. index of attraction

and no difference in moisture, to the point marking the mean values of 59.7 per cent. for the index of attraction and 292 mg. for difference in moisture output. The correlation coefficient between the indices of attraction and the differences in moisture output is 0.72, indicating that the correlation is significant at a probability level well below 0.1 per cent. The seven values for high moisture difference, which stand somewhat apart in the plotted graph, were all due to an exceptionally moist-skinned man being used in the test; it was discovered later that he was of Hungarian extraction, the Hungarians, unlike the Caucasians, having well-known Asiatic affinities. The lowest value for the index of attraction for the moister class was 45 per cent., given by a man with a very large hand; although his moisture output per hand was above average, per unit area of hand it was below average.

In a second set of experiments on the effect of moisture, one of the hands of an individual was induced to perspire and was then compared with the other hand. The right arm was introduced into a chamber of dry air at 140°F. and held there for 15 min. before being withdrawn. The skin temperature of the right hand returned to that of the other normal hand, as checked by thermocouples, within 0.5 to 10 min., depending on the individual. Then polythene bags were put on each hand to determine their moisture output; the treated hand was found to put out between 2 and 102 per cent. more than the untreated, the

TABLE VIII.

Comparison of perspiring hands (right) with normal hands (left) of Caucasians.

Moisture output (mg.)			Landing rate		Index of attraction (%)	Student's <i>t</i>
Left	Right	% Increase	Left	Right		
88	185	102	59	16	79	4.00
148	232	57	62	18	78	5.75
95	147	55	31	10	76	2.82
195	227	16	40	22	65	2.58
328	446	36	116	68	63	2.30
332	397	20	177	108	62	4.45
134	190	41	36	24	60	1.17
238	377	58	101	78	56	0.85
154	164	6	52	49	52	0.40
216	221	2	51	52	50	0.09
Entire set :			803	532	60.1	4.47

increase varying with the individual. Ten adult male Caucasians were tested, both for increase in moisture output of the treated hand, and also for the comparative attractiveness of the treated with the untreated hand. The results are shown in Table VIII.

It will be seen that the untreated hand, with the lower moisture output, was the more attractive, receiving between 50 and 79 per cent. of the total landings.

Taking the figures for the entire series, the index of attraction for the drier hands was 60.1 per cent. Statistical analysis of all the 180 counts yielded a *t* value of 4.47, indicating that the difference in favour of the untreated drier hand was very highly significant. The *t* values for the individual tests exceeded 2.30, indicating significance at the 2 per cent. levels, in the six out of the ten comparisons which showed the highest indices of attraction. Table VIII also shows that the greater the increase in moisture output of the treated hand, the greater the index of attraction of the normal hand as compared with it. The correlation coefficient of this is 0.75, and is therefore highly significant.

Discussion of Results.

The tests performed clearly show that, if the hands of two individuals differ only in skin temperature, the warmer hands attract more mosquitos to land on them. Here the differences involved between the respective skin temperatures are of the order of 2 to 3°C. In laboratory tests, DeLong & others (1945) found the human skin to be attractive to *Aedes aegypti* provided its surface temperature (34°C.) exceeded the air temperature by 2°C. or more. In field tests, Brown (1951) found that the robot with the warmer surface temperature (32°C.) was six times as attractive as the other with a lower surface temperature (13°C.). In the present experiments, normal hands at 31–34°C. were four times as attractive as hands cooled to 22–25°C. These results are comparable to those obtained with laboratory rats by Kingscote & Francis (1954), where those with a surface temperature of 30°C. were four times as attractive as those at 22°C., and nine times as attractive as those at 16°C.

It was surprising to find that hands warmed to 35–36°C. were only one-half to two-thirds as attractive as the normal, since it had previously been found that a plastic ball at 43°C. had attracted two to five times as many touches by *A. aegypti* as one at 32°C. (Peterson & Brown, 1951).

With regard to skin hue, previous work on the attractiveness of coloured surfaces (Brett, 1938; Gjullin, 1947; Brown, 1951; Brown, 1954) had demonstrated that the darker surfaces were the more attractive to adult *Aedes* mosquitos. It is thus appropriate to find not only that Negroes are more attractive than Orientals, and both more attractive than Caucasians, but also that a significantly greater attractiveness is found in dark-skinned than in light-skinned Caucasians. In these tests a wide selection of different individual Caucasians were employed, but only two Negroes and three Orientals were available for experiment.

On the other hand, it was surprising to find that hands which transpired the most moisture were the least attractive, since previous work has shown that moisture is attractive to *Aedes* mosquitos. A moist air-stream attracted 3 to 5 times as many approaches as a dry air-stream (Brown, Sarkaria & Thompson, 1951); the surface of a warmed conical flask attracted *A. aegypti* only when moistened (Parker, 1948); surface moisture increased the attractiveness of a clothed robot 2 to 4 times provided the air temperature exceeded 60°F. (Brown, 1951). With human skin it had been found (DeLong & others, 1945) that when the air temperature equalled the skin temperature (34°C.) the skin became attractive when the relative humidity of the air was reduced below 100 per cent. so that the mosquitos could detect the humidity gradient to the skin. Since the experiments here reported were performed at relative humidities between 30 and 65 per cent., there was no impairment of the humidity gradients to the skin of the hands. That the vapour emanating from the human arm is attractive to *A. aegypti* has been amply demonstrated in olfactometer experiments (DeLong & others, 1945; Willis, 1947).

No reasons can be suggested to explain why the hand of a subject that

normally transpires more moisture, or a hand which has been induced to do so, is less attractive to mosquitos. Presumably the bulk of the moisture output derives from sudoriferous glands, including the thermal sweat glands on the back of the hand, and the very abundant emotional sweat glands on the palm of the hand. Sudor, in contrast to the sebum from the axillary and inguinal regions, is deficient in volatile lipoidal compounds. It has been found (Thompson & Brown, 1955) that whereas the vapour of axillary sweat, rich in sebum, was significantly attractive to *A. aegypti*, that of sweat from the forehead, which resembles the hand in being almost entirely sudoriferous, tended to be unattractive, but the tendency was without statistical significance. It would therefore appear that the relative unattractiveness of hands which transpire more is due to factors other than, but correlated with, their higher moisture output.

Summary.

Hands of warm-skinned Caucasian individuals were significantly more attractive to *Aëdes aegypti* (L.) than cool-skinned individuals. An artificially cooled hand is very much less attractive than a normal one.

Hands of Negroes were significantly more attractive than those of Orientals, and both were significantly more attractive than those of Caucasians. Hands of dark-skinned Caucasians were significantly more attractive than those of light-skinned Caucasians.

Warmer skins were more attractive even if combined with a lighter skin hue, in Caucasian subjects. Thus skin hue is secondary to skin temperature in deciding the attractiveness of Caucasians.

Hands of individuals with low moisture output were significantly more attractive than those of high moisture output. A hand induced to perspire freely was significantly less attractive than the normal hand.

Acknowledgements.

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References.

- BRETT, G. A. (1938). On the relative attractiveness to *Aëdes aegypti* of certain coloured cloths.—Trans. R. Soc. trop. Med. Hyg., **32**, pp. 113–124.
- BROWN, A. W. A. (1951). Studies of the responses of the female *Aëdes* mosquito. Part IV. Field experiments on Canadian species.—Bull. ent. Res., **42**, pp. 575–582.
- BROWN, A. W. A. (1954). Studies on the responses of the female *Aëdes* mosquito. Part VI. The attractiveness of coloured cloths to Canadian species.—Bull. ent. Res., **45**, pp. 67–78.
- BROWN, A. W. A., SARKARIA, D. S. & THOMPSON, R. P. (1951). Studies on the responses of the female *Aëdes* mosquito. Part I. The search for attractant vapours.—Bull. ent. Res., **42**, pp. 105–114.
- DELONG, D. M. & others. (1945). Rep. nat. Res. Coun. Insect Contr. Comm., no. 176. Washington, D.C. (Abstr. curr. Inf. Insect Contr., (N.S.) nos. 3–11, 1946.)
- GJULLIN, C. M. (1947). Effect of clothing color on the rate of attack of *Aëdes* mosquitoes.—J. econ. Ent., **40**, pp. 326–327.

- KINGSCOTE, A. A. & FRANCIS, J. D. (1954). Studies on the attractancy of laboratory rats to *Aedes aegypti* L.—Environm. Prot. tech. Rep. Def. Res. Bd Can., no. 5, 23 pp.
- PARKER, A. H. (1948). Stimuli involved in the attraction of *Aedes aegypti* L. to man.—Bull. ent. Res., **39**, pp. 387–397.
- PETERSON, D. G. & BROWN, A. W. A. (1951). Studies of the responses of the female *Aedes* mosquito. Part III. The response of *Aedes aegypti* (L.) to a warm body and its radiation.—Bull. ent. Res., **42**, pp. 535–541.
- THOMPSON, R. P. & BROWN, A. W. A. (1955). The attractiveness of human sweat to mosquitoes and the role of carbon dioxide.—Mosq. News, **15**, pp. 80–84.
- WILLIS, E. R. (1947). The olfactory responses of female mosquitoes.—J. econ. Ent., **40**, pp. 769–778.
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FIG. 1. Dark (left) vs. light Caucasian (Table IV, fifth comparison).



FIG. 2. Negro (left) vs. Oriental (Table V, second comparison).



FIG. 3. Oriental (right) vs. light Caucasian (Table V, eighth comparison).

PHOTOGRAPHIC COMPARISON OF HANDS DIFFERING IN
SKIN HUE.

A NEW GENUS FOR *TORTRIX POSTVITTANA* (WALKER) AND
CERTAIN OTHER AUSTRALIAN AND NEW ZEALAND
SPECIES (LEPIDOPTERA: TORTRICIDAE).

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(PLATES II & III.)

The Apple Leaf Roller or Light Brown Apple Moth, as *Tortrix postvittana* (Wlk.) is commonly known, is a common pest of apple and citrus orchards in Tasmania and in coastal regions of Australia. It occurs also in New Zealand and the Hawaiian Islands, probably as a result of accidental importation, and a small colony has existed at Newquay in the south-west of England for the last twenty years or so.

In Australia, *postvittana* is typical of a large group of species at present placed in the genus *Tortrix* Linnaeus. This follows Meyrick's classification of the TORTRICIDAE (1913). Previous to that, *postvittana* had been in *Archips* Hübner and *Cacoecia* Hübner; it has also been placed in *Eulia* Hübner and, when first described by Walker, in *Teras* Treitschke. Several of its synonyms were described in *Dichelia* Guenée, and another in *Pandemis* Hübner. Not one of these genera is tenable for the *postvittana* group. Recent work has shown that these species should be removed from their present position in the tribe Tortricini, and placed in a genus of their own in the Archipsini (defined by Obratzsov, 1954).

Austrotortrix new genus

Head (fig. 1) with lower part of front thinly, and upper part densely scaled, crown with dense loosely appressed scales projecting between antennae and above vertex. Male antenna weakly serrate, finely ciliated, cilia about as long as width of antennal shaft, shaft clothed with scales dorsally. Antennal scape short,



Austrotortrix postvittana (Walker).

Fig. 1.—Lateral view of head, showing labial palpi.
Fig. 2.—Wing venation,

moderately scaled. Compound eye rather large and prominent. Ocellus well removed from antennal socket, adjacent to compound eye. Labial palpus directed more or less straight in front or subascending; basal segment short; middle segment long, roughened beneath, somewhat roughened and dilated above; terminal segment short, porrect, subacute. Tongue well developed. Thorax smooth-scaled, without a posterior crest. Tegula (not denuded) long, nearly reaching to suture of meso- and metathorax. Patagia very small. Legs strong, spurs long, hind tibia clothed with bristly lance-like scales. Abdomen reaching a little beyond hind wing, a small anal tuft present in the male.

Forewing (fig. 2) elongate rectangular, with a small costal fold in the male, costa arched to $1/2$ in male and to $1/4$ in female, straight or slightly incurved before apex, termen straight or slightly sinuate above, shortly rounded at tornus, dorsum straight or slightly curved, a small scale-projection near base. Vein 1b with basal furcation to about $2/5$, 1c present at margin, 2 from $2/3$ of cell, 3 from angle and strongly curved, veins 3 to 7 well spaced and almost parallel, 10 from $3/4$ of cell, 11 from a little before $1/2$, 12 with strong precostal vein.

Hind wing (fig. 2) semioval, termen scarcely sinuate above, vein 1a present, 1b furcate at base, veins 3 and 4 connate at angle, 5 connate or approximate to 4, veins 6 and 7 separate or shortly stalked or anastomosed near base, 8 anastomosed with radius near base or connected by a short cross-vein. A hair pencil arising from the base of the hind wing in the male.

In some specimens examined, aberrant stalking of the distal extremity of a vein was found, and the specimen which was used for the venation drawing in fig. 2 has vein 1a in the hind wing aberrantly forked at the margin. Normally vein 3 of the forewing is strongly curved, more so than in other Australian genera nearly related.

Male genitalia with basal part of valva broad, inner side hairy and in some species bearing specialised scales; distal part of valva developed into a delicate digitate cucullus; sacculus distinct and strong, sometimes serrate. Juxta a somewhat angular or heart-shaped plate. Uncus varying from truncate to spatulate, haired beneath. Gnathus arms blade-like, apices fused and forming a hook mid-ventrally. Socii reduced to vestigial plates. Aedeagus straight or slightly curved, with deciduous cornuti.

Female genitalia with ovipositor lobes elongate, rather narrow and moderately hairy. Ostium opening varying from wide to narrow, with a sclerotised rim. Ductus bursae long, a little dilated towards bursa; without a cestum. Bursa copulatrix spheroidal, often with a prominent thorn-like signum bearing a capitulum—as in *postvittana*—but sometimes without a signum. Both pairs of apophyses short.

Type species: *Austrotortrix postvittana* (Walker) (*Teras postvittana* Walker, 1863).

This genus has characteristics of the *Archips*—*Adoxophyes* group, and can be placed systematically near to *Isotenes* Meyrick and *Harmaloga* Meyrick.

Austrotortrix postvittana (Walker), **new combination.** (Pl. II, fig. 1.)

Teras postvittana Walker, 1863, List Lep. Ins. B.M., 28, p. 297.

Teras scitulana Walker, 1863, List Lep. Ins. B.M., 28, p. 299. (Pl. II, fig. 2.)

Teras basialbana Walker, 1863, List Lep. Ins. B.M., 28, p. 299. (Pl. II, fig. 3.)

Teras secretana Walker, 1863, List Lep. Ins. B.M., 28, p. 300.

Pandemis consociana Walker, 1863, List Lep. Ins. B.M., 28, p. 311. (Pl. II, fig. 4.)

Dichelia reversana Walker, 1863, List Lep. Ins. B.M., 28, p. 321. (Pl. II, fig. 5.)

Dichelia retractana Walker, 1863, List Lep. Ins. B.M., **28**, p. 322. (Pl. II, fig. 6.)

Dichelia foedana Walker, 1863, List Lep. Ins. B.M., **28**, p. 326.

Dichelia vicaureana Walker, 1869, Characters undescr. Lep. Het., p. 82.

Tortrix pyrrhula Meyrick, 1910, Proc.Linn.Soc.N.S.W., **35**, p. 226. (**Syn. nov.**).

Lectotype ♂ "Port Lincoln, S.Australia, 5.11.82" Genitalia prep. B.M.1817.

Tortrix dissipata Meyrick, 1922, Exotic Microlepidoptera, **2**, p. 496. (**Syn. nov.**).

Type ♂ "Yallingup, C.Naturaliste, S. W-Australia, 12.1913, Turner" Genitalia prep. J.F.G.C.9354.

With the exception of *vicaureana*, which is in the Melbourne Museum, the types of the above synonyms of *postvittana* are in the British Museum (Natural History). They have been studied during the course of the present work, and *consociana* and *retractana* were found to be males, though described by Walker as females, and *foedana* female, though originally described as a male.

The coloration and wing markings of the adults of *postvittana* are very variable, a fact indicated perhaps by the extensive synonymy. In Australia, where there are a number of other species closely resembling *postvittana* and often exhibiting considerable variation, identification can sometimes be an uncertain matter. In many cases, positive identification can best be achieved through examination of the genitalia. Descriptions and illustrations of the morphology of these structures are therefore appended for that purpose.

Male genitalia (Pl. III, figs. 2a & 2b). Basal half of valva strongly arched at costa, inner side thinly clothed with long hair-like setae; distal half of valva (cucullus) weak and flap-like; sacculus strongly sclerotised, broad, tapering distally. Gnathus in the form of a shallow sharply pointed hook. Transtilla broad laterally, dorsal ridge sclerotised and almost straight, bristling with thorn-like projections varying in number and size and mostly on the lateral shoulders of the transtilla. Juxta heart-shaped, usually with a fairly deep median cleft on the posterior edge and with the anterior edge slightly produced to a point, but often showing variation between individual specimens. Aedeagus straight, slightly broader and curved a little basally, with three large deciduous cornuti (appearing as one in Pl. III, fig. 2b).

Female genitalia (Pl. III, figs. 1a, 1b & 1c). Ovipositor lobes fairly large, a little dilated inwardly. Ostium membranous, wide at the mouth and with a narrow, strongly sclerotised and somewhat uneven rim. Colliculum bilamellate. Ductus bursae long, widening almost immediately beyond the colliculum, at the inception of the ductus seminalis, to about twice its width and dilating slightly to enter the bursa copulatrix. Bursa copulatrix with a strong thorn-like signum bearing a prominent capitulum in the form of a bulbous knob. The form of the signum seems to be characteristic for *postvittana*, but it varies considerably in shape and robustness, sometimes appearing as a strong curved hook and at other times only gently curved and gradually tapering to a slender and almost straight point. The capitulum is also variable in shape and may be spherical or elongate.

Listed below are some of the species congeneric with *postvittana* and accordingly assigned to *Austrotortrix*. For some of them lectotypes are designated since types were not indicated by the original author. Types and lectotypes of all the species listed are in the British Museum (Natural History).

Austrotortrix dotatana (Walker), **new combination.**

Teras dotatana Walker, 1863, List Lep. Ins. B.M., **28**, p. 298.

Type ♀ Genitalia prep. B.M. 1814.

This species is superficially very like *postvittana* but is much larger. The

wing expanse of the type is 31 mm., while the type of *postvittana* measures 21 mm.

Austrotortrix tanyptera (Meyrick), **new combination.**

Tortrix tanyptera Meyrick, 1910, Proc.Linn.Soc.N.S.W., **35**, p. 228.

Described from five specimens, two of which are in Meyrick's collection in the British Museum. The latter are females and unfortunately are without abdomens. They appear to be conspecific with *dotatana*, and I have therefore refrained from selecting one of them as a lectotype as it seems desirable that the other three specimens should first be examined to make certain whether or not the name can be retained.

Austrotortrix sobriana (Walker), **new combination.**

Dichelia sobriana Walker, 1863, List Lep. Ins. B.M., **28**, p. 322.

Type ♀ Genitalia prep. B.M. 1979.

In this species the bursa copulatrix of the female is without a signum.

Cacoecia jugicolana Meyrick, 1882, Proc.Linn.Soc.N.S.W., **6**, p. 499. (**Syn.nov.**)

Lectotype ♀ "Murrurundi, N.S.Wales, G.H.R. bred .79" Genitalia prep. B.M.1956.

Cacoecia fabricata Meyrick, 1910, Proc.Linn.Soc.N.S.W., **35**, p. 233. (**Syn. nov.**)

Lectotype ♂ "Lorne, Victoria, G.L. 5.3.06" Genitalia prep. B.M.2424.

Austrotortrix mnemosynana (Meyrick), **new combination.**

Cacoecia mnemosynana Meyrick, 1882, Proc.Linn.Soc.N.S.W., **6**, p. 504.

Lectotype ♂ "Bulli Pass, N.S.Wales, 1.10.78" Genitalia prep. B.M.1964.

This species is distinct from *Tortrix sobriana* (Walker, 1863) under which it has previously been synonymised.

Cacoecia psapharana Meyrick, 1883, Proc. Linn.Soc.N.S.W., **7**, p. 174. (**Syn. nov.**)

Lectotype ♂ "Launceston, Tasmania, 29.1.82" Genitalia prep. B.M.1976.

Austrotortrix liadelpha (Meyrick), **new combination.**

Tortrix liadelpha Meyrick, 1910, Proc.Linn.Soc.N.S.W., **35**, p. 227.

Lectotype ♂ "Albany, W. Australia, 3.10.86" Genitalia prep. B.M.1810.

Austrotortrix acraria (Meyrick), **new combination.**

Tortrix acraria Meyrick, 1910, Proc.Linn.Soc.N.S.W., **35**, p. 231.

Lectotype ♂ "Deloraine, Tasmania, 28.12.04" Genitalia prep. B.M.1955.

Austrotortrix lycodes (Meyrick), **new combination.**

Tortrix lycodes Meyrick, 1910, Proc.Linn.Soc.N.S.W., **35**, p. 232.

Lectotype ♂ "Mt. Wellington, Tasmania, 2,500 ft., 3.12.82" Genitalia prep. B.M. 1811.

Austrotortrix xylodes (Meyrick), **new combination.**

Tortrix xylodes Meyrick, 1910, Proc.Linn.Soc.N.S.W., **35**, p. 224.

Lectotype ♂ "Mt. Victoria, N.S.Wales, 6.11.84" Genitalia prep. B.M. 2000.

Austrotortrix philopoana (Meyrick), **new combination.**

Tortrix philopoana Meyrick, 1882, Proc.Linn.Soc.N.S.W., **6**, p. 515.

Lectotype ♂ "Hamilton, New Zealand, 15.1.80" Genitalia prep. B.M. 2050.

Austrotortrix cavillata (Meyrick), **new combination.**

Tortrix cavillata Meyrick, 1922, Exotic Microlepidoptera, **2**, p. 497.

Type ♂ "Melbourne, Victoria, 10.1892, Anderson" Genitalia prep. J.F.G.C.9353.

Summary.

A new genus, *Austrotortrix*, is erected for *Teras postvittana* Walker, the Apple Leaf Roller or Light Brown Apple Moth, a common pest of apple and *Citrus* in the coastal regions of Australia, and in Tasmania and New Zealand.

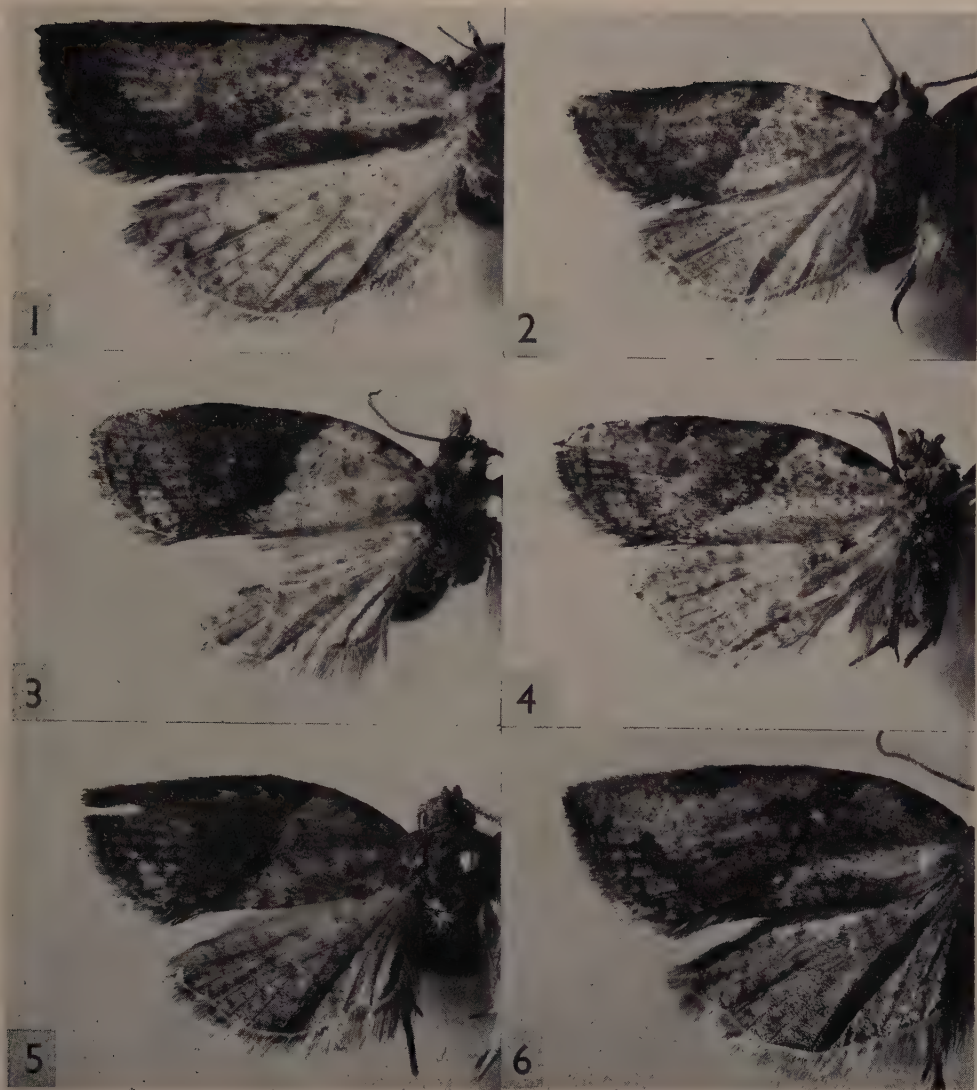
Two new synonyms of *A. postvittana* in addition to those already recorded are given.

As there are several species in Australia closely resembling *postvittana*, making identification difficult, descriptions of the genitalia of *postvittana* are given as these provide the best means of positive identification.

Apart from the type species, *postvittana*, ten other species are assigned to the new genus.

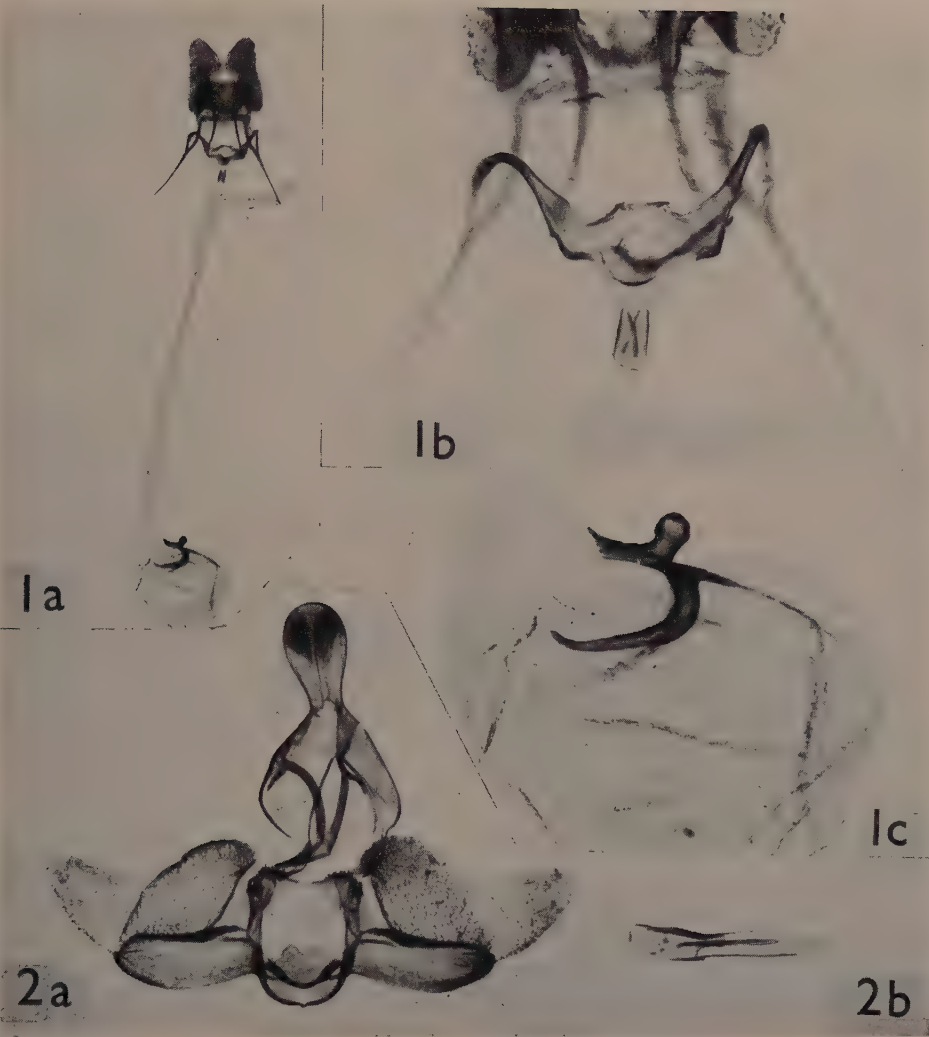
References.

- MEYRICK, E. (1913). Genera Insect., **149**, pp. 27-34.
OBRAZTSOV, N. (1954). Tijdschr. Ent., **97**, p. 150.
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Austrotortrix postvittana (Walker), n. comb. and some synonyms.

FIG. 1. *A. postvittana* (Walker), type ♀. SYNONYMS: FIG. 2. *scitulana* (Walker), type ♂; FIG. 3. *basialbana* (Walker), type ♂; FIG. 4. *consociana* (Walker), type ♂; FIG. 5. *reversana* (Walker), type ♂; FIG. 6. *retractana* (Walker), type ♂. (All magnified approximately 6 times.)



Genitalia of *Austrotortrix postvittana* (Walker).

FIG. 1a. Ventral view of female genitalia (type). FIG. 1b. Enlargement of ostium and colliculum. FIG. 1c. Enlargement of signum and capitulum. FIG. 2a. Ventral view of male genitalia. FIG. 2b. Aedeagus.

R
A CULTURE METHOD FOR *CULICOIDES NUBECULOSUS*
(MEIGEN) (DIPTERA: CERATOPOGONIDAE) IN THE
LABORATORY, WITH NOTES ON THE BIOLOGY. S.S.

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Hill (1947) reviewed four previous attempts to breed species of *Culicoides*, including *C. nubeculosus* (Mg.), in the laboratory; these met with varying, but never complete success, none of the species studied being maintained for more than one generation. Hill herself reared *C. impunctatus* Goetgh. and *C. obsoletus* (Mg.) in the laboratory in pots containing the medium in which each species was found to breed in nature. She was, however, dependent for eggs upon wild females, already gravid or fed in the laboratory. With the exception of two *C. impunctatus* and one *C. obsoletus*, no laboratory-reared females survived long enough to lay eggs.

The only species which, up to now, has been maintained successfully in the laboratory is *C. nubeculosus*. A strain of this species, collected near Chideock, Dorset, was established in the Department of Zoology, University of Glasgow, by Mr. J. A. Downes in 1947. The basis of his method was to simulate the natural habitat of the species. Richly manured soil was collected near a byre on a farm near the field-station at Loch Lomond, and either used at once, or spread on trays to dry, stored, and made up with water when required. The mud thus obtained was kept in unglazed earthenware pots, filled to a depth of several inches, which were stood in a basin of water and exposed to an electric lamp until a fair algal growth formed. Eggs or first-instar larvae of *C. nubeculosus* were then introduced into the culture pot, which was kept well lit at 20°C.

The strain of *C. nubeculosus* established was successfully maintained, except for one hiatus, from 1947 to mid-1953, when it began to show symptoms of deterioration. The gravid females refused to lay their eggs, and the size of egg-batch and the percentage that hatched became smaller. This deterioration may have been an after-effect of the culture method described below, but it is more probably due to prolonged inbreeding without introduction of new blood. The culture is now (January 1955) extinct.

Technique.

Materials.

When the present author took over the culture, in 1951, it was found that to induce algal growth was tedious and uncertain, and that, consequently, larval mortality was high. Only a few adults emerged, many of them undersized, and they were just sufficient for re-stocking. This suggested that the medium was in some way deficient. With the object of improving algal growth, powdered charcoal and dried autolyzed yeast were added to the mud, and fairly large numbers of adults were then obtained. The yeast presumably enriched the medium directly, in virtue of its content of growth-stimulating factors (vitamins of the B-complex), and indirectly, by encouraging the growth of bacteria and other micro-organisms; in several cases rich algal growth also occurred. The yeast used was "Dried Autolyzed Yeast—D.C.L.—Distillers, Edinburgh", and the mud was obtained from the original source. To prepare the mud, it was spread out on a tray in the laboratory and left to dry. It was then powdered in

a mortar, passed through a sieve (10 meshes per inch) to exclude gravel, etc., and stored until required. The pots used were of unglazed earthenware and six inches in diameter by one inch high, without a drainage hole.

Preparation of the culture pots.

Following preliminary trials, a simple and satisfactory method was developed. Each pot was filled to a depth of approximately 4 mm. with a mortar-ground mixture of about 50 gm. powdered mud, 6 gm. dried autolyzed yeast and 4 gm. powdered charcoal. Sufficient water was then added, without stirring, to give standing water at least over depressions in the surface of the mud. The pots were then transferred to an insect-proof cage in the open. This is necessary because Psychodids will breed heavily in this medium, and because the decaying yeast has an offensive odour. The culture pots should be prepared about three weeks before they are required, the medium being kept well watered and stirred occasionally, as necessary, to prevent the formation of a skin by the yeast that rises to the surface within about a week. This skin frequently encourages fungal growth which, when great, is unfavourable to the larvae.

Rearing method.

The laboratory temperature was maintained fairly constant at 20°C., though it sometimes reached 25°C. during hot spells, and usually dropped below 20°, but rarely below 15°C., during very cold ones.

The pots were brought in and stocked with recently hatched larvae. Larvae were introduced in preference to egg-batches because the latter very frequently fail to hatch, and because it was desirable to know the number of larvae added to each pot and the percentage that succeeded in emerging as adults, and also the percentage of eggs that hatched in the laboratory. The number of larvae introduced into each pot varied from 70 to 220. The stocked pots should not be disturbed, and should be so irrigated as to avoid desiccation of the medium, without letting the layer of water reach the edges of the pot and the larvae thus escape. From the beginning of the third week only a thin layer of water is needed; much water at this time hampers pupation, and may damage some of the emerging adults. Any fungal growth on the wall of the pot should be wiped off, as newly emerged adults may become entangled in it.

After stocking, each pot was stood in an empty basin, to collect drainage water, in a rearing cage, consisting of a glass tank $11\frac{1}{2} \times 11\frac{1}{2}$ in. and 20 in. high, laid on its side, with the mouth covered with muslin. It was found inadvisable to surround the pots with water to lessen evaporation, as many adults thereby drowned. A source of light should be provided at one end of the cage when it is opened, to facilitate the collection and to prevent the escape of the adults which are phototropic.

It is interesting that two salt-marsh species of *Culicoides* have been reared successfully by this method. Recently hatched larvae of *C. halophilus* Kieff., obtained from eggs laid in the laboratory by wild gravid females, thrived well in the medium described, and many of them reached the adult stage. Similar results were obtained by my colleague, Mr. P. Becker, with *C. circumscriptus* Kieff., using first-instar larvae obtained in the same way, and advanced larvae obtained from the field. It is probable, therefore, that if the difficulty in inducing mating and feeding in the laboratory can be overcome, other species of *Culicoides* can be established as laboratory cultures on this medium. Another use of it would be to facilitate the study of the morphology, anatomy and systematics of the early stages of species of *Culicoides*. It is undoubtedly easier to rear larvae obtained from eggs laid in the laboratory by wild gravid females of known identity, than to collect samples of the natural habitat and sieve out the larvae for study.

Maintenance of adults.

The emerging adults were kept in a collecting cage, which was similar to the rearing cages but contained several petri dishes with a layer of wet cotton-wool covered by filter paper, to provide moisture and maintain a relative humidity of 80-90 per cent., and some raisins.

Feeding.

The females of *C. nubeculosus* feed readily in the laboratory. Downes (1950) states that they will not bite until two to three days old, and Roberts (1950) that they will take their first blood meal three days after emergence; in the writer's experience, a proportion may feed the first day after emergence, and some may not feed at all. It was found easier to feed the adults on the writer's arms, which are not very sensitive to the bites, than to use a rabbit or the method described by Roberts (*ibid.*). The females (and also males, to ensure mating) were sucked into a 3 × 1-in. tube which was then inverted on the underside of the forearm. One should not use many adults per tube: during and for some time after feeding, the females drain themselves and, if there are many insects in one tube, they become stuck to the condensation water on the walls and so are damaged.

Mating.

Mating takes place readily in 3 × 1-in. tubes and rarely in the cage. As observed by Pomerantsev (1932) and Downes (*ibid.*), mating can take place while the females are feeding. It is certain that mating is independent of a blood-meal as Hill (*ibid.*) suggests is the case with *C. impunctatus* and *C. obsoletus*.

Egg production.

A full blood-meal is necessary for the development of the ovaries. In rare cases, however, females which had fed on blood to satiety had undeveloped ovaries. The females of *C. nubeculosus* feed only once in each gonotrophic cycle. According to Hill (*ibid.*), individual females of *C. impunctatus* and *C. obsoletus* have been recorded as taking up to seven and five blood-meals, respectively, although similar numbers of eggs were laid after one meal as after more than one. Sharp (1928) suggested the possibility that *C. austeni* C., I. & M. requires two blood-meals to complete ovulation.

For egg-laying, 3 × 1-in. tubes with a layer of plaster of paris at the bottom were used. The plaster was moistened and covered with a disc of filter paper, and a further strip of filter paper inserted. Two fed females and two males were put into each tube, which was fitted with a muslin-covered bored cork, having a small piece of raisin pinned to its inner surface. It was found that with only one female and one male per tube, the female often refused to lay eggs; this confirms the observations of Downes (*ibid.*). The tubes were kept in the laboratory at 80-90 per cent. relative humidity. The eggs are laid on the disc of filter paper; the gravid females will never lay their eggs on a dry surface, and it is essential, therefore, that the plaster and the disc of filter paper be kept moist. It was observed that the presence of males is not essential if the females have already mated. Fertilised females laid eggs as usual, in the absence of males. However, it saved labour to put the males with the females in the egg-laying tubes; copulating pairs were frequently seen in these tubes and most of the females undoubtedly mate more than once before they lay their eggs. Contrary to what is suggested by Gad (1951), sugars are not essential for ovulation. Blood-fed females which had no access to raisin laid viable eggs, but it was supplied as a source of energy, especially for males.

When sectioned, the oocytes appeared to be fully developed in flies fixed three days after a full blood-meal. The period between feeding and oviposition varied from 3-16 days, but was commonly 3-4. Downes (*ibid.*) found it to be 4-5 days, and Roberts (*ibid.*), 2-3. However, no female was encountered which laid its eggs two days after a meal, and in sections of females fixed two days after feeding, the oocytes were always oval and never, as in flies fixed three days after the meal, banana-shaped. A good number of the gravid females frequently refused to lay eggs.

The number of eggs laid per batch varied from 40-206, with an average of about 135. Roberts (*ibid.*) states that females fed on man laid an average of 380 eggs, but she did not mention whether this was the number per batch or the total eggs laid in several batches; in the writer's experience it is too large for one batch. Oviposition was usually complete, but occasionally from 1 or 2 up to 70 eggs were retained. According to Hill (*ibid.*), *C. impunctatus* may on rare occasions retain 1-2 eggs. In *Simulium damnosum* Theo., some eggs often remain behind after oviposition, sometimes 2 or 3, as in mosquitos, and sometimes up to 20 or more (Lewis, 1953). Immature eggs (white or grey) were occasionally laid.

As stated by Downes (*ibid.*), the females are ready to bite after oviposition and in due course to lay again. In the present work, however, the females in each tube were dissected as soon as eggs were seen on the disc of filter paper, to see whether the laid eggs belonged to one or both females, and also to see if oviposition was complete or if there were any eggs retained.

The disc of filter paper bearing the eggs was transferred to a solid watch-glass, the eggs being kept just moist for the first two days and then covered with a thin film of water. The watch-glass cover was smeared with petroleum jelly, to prevent evaporation and consequent desiccation of the eggs, the edges of the watch-glass being wiped clean before the hatched larvae were turned into the pots. The eggs commonly hatched 3-4 days, but sometimes up to 6 days, after oviposition; the minimum time as calculated by Lawson (1951) is more than 48 but less than 65 hours. The percentage of eggs that hatched in each batch varied from 26-96, the average being about 55; Downes (*ibid.*) found that more than 80 per cent. of the eggs hatch. It should be noted that batches of eggs frequently fail to hatch and, sometimes, only a few eggs may hatch. Parker (1950) suggested that some artificiality in the laboratory environment, acting either directly on the eggs, or indirectly through the parent, may be responsible for such high mortality. The viable eggs of any batch usually hatch within a short time of each other, but this period may occasionally extend to 1 or 2 days.

The Life-cycle as studied in the Laboratory.

The life-cycle may vary considerably between individuals derived from the same batch of eggs: while adults were emerging from a given culture pot, third- and fourth-instar larvae might still be seen. The egg stage usually occupied 3-4 days (see above), and the pupal stage about 4 days, though in rare cases it lasted about a week. The variation in life-cycle is due to the larvae developing at different rates; Hill (*ibid.*) found the same feature in *C. impunctatus*.

In January-October, the period from the beginning of the first larval instar to the emergence of the first adult varied from 18-36 days in different pots and the corresponding period for the last adults varied from 30-57 days; the total period over which emergence from any given pot extended was from 7-35 days. Adding the period occupied by the egg stage, the earliest-emerging adults completed their life-cycle in from three to six weeks, and the latest-emerging adults completed it in from $4\frac{1}{2}$ to $8\frac{1}{2}$ weeks.

The larvae obtained during October, however, commonly took a long time for their transformation. A very few adults emerged in the normal time, but otherwise emergence only began in late December, January or February. As stated previously, the laboratory temperature fell in winter, but rarely below 15°C. It is not known whether it was this drop in temperature, or the short length of day, that was responsible for this delayed development; at any rate, the larvae did not become dormant and could be seen feeding or swimming at the surface of the medium. The period from the beginning of the first larval instar to the emergence of the first adult varied from 38–75 days in different batches and the corresponding period for the last adults varied from 85–124 days. In other words, the earliest-emerging adults completed their life-cycle in from six to 11 weeks and the latest-emerging adults completed it in from 13–18 weeks. The period over which emergence from any given pot occurred varied from 14–82 days.

Roberts (*ibid.*) gives the life-cycle as four to five weeks, and Downes (*ibid.*) gives the minimum as three weeks; these figures undoubtedly apply only to the earliest adults emerging from batches in January–October. In general, from six to eight generations of *C. nubeculosus* can be obtained in the laboratory each year, the last generation, derived from the October larvae, usually occupying several months.

The number of the adults emerging from any culture pot varied from 23–100, or, expressed as a percentage of the larvae introduced, from 17–91, with an average of 45 per cent. The number of larvae introduced per pot (within the range 70–220) does not appear to affect the percentage or the period of emergence. The first adult to emerge may be a male or a female; Hill (*ibid.*) found with *C. impunctatus* and *C. obsoletus* that the first flies to hatch from a given batch of eggs were all males.

Behaviour of the Immature Stages in the Culture Pots.

Larvae.

The observations of larval activity are facilitated by a free water-surface; those described here were made on third- and fourth-instar larvae. The larvae spend the greater part of their life in burrows at the surface of the substratum, with the head, some or all of the thorax and usually some or most of the abdominal segments protruding. The larvae sometimes leave their tunnels and can be seen creeping on the substratum or the wall of the pot, or swimming freely at the water-surface. In the less inundated parts of the substratum the larvae are usually buried except for the head, and the mouth-parts can be seen working through the surface as vibrating dots.

The larvae of *C. nubeculosus* are phototropic, and show conspicuous activity when the pot is exposed to an electric light. They are very easily alarmed and the slightest jarring or vibration makes them withdraw rapidly into their tunnels. Carter, Ingram & Macfie (1920) describe similar activities in the larvae of *C. accraensis* C., I. & M.

The larvae commonly concentrate their feeding on the surface and top few millimetres of the substratum, and at the water-surface, and this seems to occupy most of their time. They feed with little discrimination on the considerable variety of living and non-living organic matter that is available. The culture pots studied contained amorphous organic matter, a little growth of algae and a very little of fungi with white hyphae and occasional sporangia, a film of bacteria and infusions of ciliates and flagellates. Larvae were not observed to feed on the fungus spores or the protozoa, although the dead bodies of the latter may contribute to their nourishment. However, the larvae certainly avail themselves of the other matter mentioned, and the bacterial film is

especially eaten. The greenish colour of the faeces may indicate the indigestibility of at least some of the ingested algae or green flagellates. Rodina (1949) states that the rôle of bacteria in the nutrition of Chironomid larvae is very great. Atkin & Bacot (1917) and Rozeboom (1935) point out the importance of bacteria for the normal development of mosquito larvae. In their indiscriminate feeding habits, the larvae of *C. nubeculosus* resemble Anopheline larvae (Coggeshall, 1926; Senior-White, 1928).

In the flooded spots the larva protrudes the greater part of its body from the burrow, moving it in every direction and bending the head upwards or downwards and working the mouth-parts through the iridescent film of micro-organisms at the water-surface, consisting mainly of bacteria, with infusions of ciliates and flagellates. Larvae that have left their tunnels will browse on algal and small fungal growths on the wall of the pot or on organic matter on the surface of the substratum. The behaviour of larvae in the spots that are not covered by water is exactly the same, except that the larvae either withdraw the whole of the body and appear in another spot, or leave the tunnel, creep on the surface and tunnel again in the new spot.

The larva is very restless while feeding, and from time to time shifts its feeding site within a circle of about one cm. diameter. Because of this restlessness, it was found very difficult to observe the feeding mechanism. All that could be observed was that the surface of the medium was vibrating, indicating the movements of the head and mouth-parts. It was possible to see, through the head-capsule, the piston-like movements of the epipharynx described by Lawson (1951) in *Tetrphora* (= *Dasyhelea*). The bolus is very easily seen through the integument, and as in *Tetrphora*, it moves slowly and smoothly through the fore-gut until it reaches the stomodaeal valve (at the posterior end of the metathorax), where it remains for a little while before being admitted into the mid-gut. The bolus varies in colour according to the substance eaten. More than one bolus, of different colours, and separated by a conspicuous space, can be seen passing down the oesophagus.

Pupae.

The pupae, which are initially white and later pigmented, are usually seen partly buried in tunnels in damp but not inundated spots of the substratum, with the breathing trumpets and sometimes also the cephalothorax protruding. They can also be found on the surface of the medium, usually with the end of the abdomen buried, and not uncommonly, on the wall of the pots in different positions with some of the body or spines in contact with it. It is interesting to note that the adults emerged successfully from such pupae, even when they were anchored to the wall by the caudal spines only, and it appears that a very moist substratum is not essential for their welfare.

When water is added to the culture medium, the pupae struggle to leave their tunnels, or the surface of the medium if they are lying on it, to keep away from the water. When buried, the pupa swings the cephalothorax, and wriggles the abdomen to free itself from its tunnel and struggles through the layer of water. At intervals the breathing trumpets penetrate the water-surface. Some pupae contrive to move while on their sides on the surface of the culture medium by forward contractions and expansions of the abdomen, aided by the abdominal spines. Others, while in the water, curve the abdomen till the caudal segment reaches nearly the middle of the venter of the abdomen, then release it suddenly so as to push themselves forwards.

If the pupa reaches a spot above water level or one with a very thin layer of water, it begins to tunnel there, working the caudal and abdominal spines by wriggling movements of the abdomen, and then pushing itself gradually into the excavation. On the other hand, if the pupa reaches the wall of the pot

it climbs it, aided by the abdominal spines and by the movements of the abdomen, and attaches itself in a suitable position. Patton (1913) states that the pupa of *C. kiefferi* Patt. anchors itself by two prominent terminal spines, or floats on the surface. Carter, Ingram & Macfie (1920) state that the pupae of *C. accraensis* are aquatic and float in a vertical position with the body extended and the trumpets in contact with the surface: if stranded on the sides of a glass vessel, they could wriggle back to the water over a distance of at least one inch, using antero-posterior and lateral motions of the abdomen; the pupae observed did not anchor themselves by the processes at the posterior end of the abdomen.

In the present observations, none of the pupae floated at the water-surface, but when two pupae, less than one day old, were transferred to a specimen tube containing water, they floated at the surface beside the wall of the tube, with the breathing trumpets penetrating the water-surface or inclined from it, and rose to the surface again after inversion. After four days, two female adults emerged and took wing successfully.

Summary.

A simple method for culturing *Culicoides nubeculosus* (Mg.) in the laboratory is described, the medium used for rearing the larvae being a mixture of powdered mud from near a farm byre, dried autolyzed yeast and powdered charcoal, in the proportions 25:3:2. A layer of the mixture 4 mm. deep was spread over the bottom of unglazed earthenware pots, 6 in. diam. \times 1 in. high, and just covered with water. After about three weeks in an insect-proof cage in the open, the pots were brought into the laboratory, the temperature of which was maintained at 20°C. except for brief periods in very hot or very cold weather. Each pot was stocked with from 70 to 220 newly hatched larvae, derived from a single batch of eggs laid on moist filter-paper discs in 3 \times 1-inch glass mating tubes by adults that had been fed on human blood and provided with raisins. The surface of the medium became covered with a growth of bacteria, algae, fungi, and protozoa, which provided a source of food for the larvae. These made shallow burrows in the substratum from which they partially emerged to feed and in which they pupated. About 45 per cent. of those introduced emerged successfully as adults.

The incubation and pupal periods lasted 3-6 and about 4-7 days, respectively. The time taken for larval development varied greatly between individuals from the same batch of eggs, and also between batches started at different times of year. The complete life-cycle of examples started as larvae in January-September was thus 3-8½ weeks, the period over which emergence occurred amongst a single batch being 1-5 weeks; the corresponding figures for those started as larvae in October were 6-18 and 2 to nearly 12 weeks.

The behaviour in the various stages is briefly described.

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References.

- ATKIN, E. E. & BACOT, A. (1917). The relation between the hatching of the eggs and the development of the larvae of *Stegomyia fasciata* (*Aedes calopus*), and the presence of bacteria and yeasts.—*Parasitology*, **9**, pp. 482–536.
- CARTER, H. F., INGRAM, A. & MACFIE, J. W. S. (1920). Observations on the Ceratopogonine midges of the Gold Coast with descriptions of new species. Part I.—*Ann. trop. Med. Parasit.*, **14**, pp. 187–210.
- COGGESHALL, L. T. (1926). Relationship of plankton to Anopheline larvae.—*Amer. J. Hyg.*, **6**, pp. 556–569.
- DOWNES, J. A. (1950). Habits and life-cycle of *Culicoides nubeculosus* Mg.—*Nature*, Lond., **166**, pp. 510–511.
- GAD, A. M. (1951). The head-capsule and mouth-parts in the Ceratopogonidae (Diptera—Nematocera).—*Bull. Soc. Fouad 1er Ent.*, **35**, pp. 17–75.
- HILL, M. A. (1947). The life-cycle and habits of *Culicoides impunctatus* Goetghebuer and *Culicoides obsoletus* Meigen, together with some observations on the life-cycle of *Culicoides odibilis* Austen, *Culicoides pallidicornis* Kieffer, *Culicoides cubitalis* Edwards and *Culicoides chiopterus* Meigen.—*Ann. trop. Med. Parasit.*, **41**, pp. 55–115.
- LAWSON, J. W. H. (1951). The anatomy and morphology of the early stages of *Culicoides nubeculosus* Meigen (Diptera: Ceratopogonidae=Heleidae).—*Trans. R. ent. Soc. Lond.*, **102**, pp. 511–570.
- LEWIS, D. J. (1953). *Simulium damnosum* and its relation to onchocerciasis in the Anglo-Egyptian Sudan.—*Bull. ent. Res.*, **43**, pp. 597–644.
- PARKER, A. H. (1950). Studies on the eggs of certain biting midges (*Culicoides* Latreille) occurring in Scotland.—*Proc. R. ent. Soc. Lond.*, (A) **25**, pp. 43–52.
- PATTON, W. S. (1913). *Culicoides kiefferi*, n. sp.: a new Indian blood-sucking midge.—*Indian J. med. Res.*, **1**, pp. 336–338.
- POMERANTSEV, B. I. (1932). Morphology and anatomy of the genitalia of *Culicoides* (Diptera—Nematocera). [*In Russian.*]—*Mag. Parasit.*, **3**, pp. 183–214.
- ROBERTS, E. W. (1950). Artificial feeding of *Culicoides nubeculosus* in the laboratory.—*Nature*, Lond., **166**, p. 700.
- RODINA, A. G. (1949). The rôle of bacteria in the nutrition of the larvae of Tendipedids. [*In Russian.*]—*Dokl. Akad. Nauk SSSR*, (N.S.) **67**, pp. 1121–1123.
- ROZEBOOM, L. E. (1935). The relation of bacteria and bacterial filtrates to the development of mosquito larvae.—*Amer. J. Hyg.*, **21**, pp. 167–179.
- SENIOR-WHITE, R. (1928). Algae and the food of Anopheline larvae.—*Indian J. med. Res.*, **15**, pp. 969–988.
- SHARP, N. A. D. (1928). *Filaria perstans*; its development in *Culicoides austeni*.—*Trans. R. Soc. trop. Med. Hyg.*, **21**, pp. 371–396.
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OBSERVATIONS ON ANOPHELINE MOSQUITOS OF THE AKAH RIVER, 4th DIVISION, SARAWAK.

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The observations recorded below were made on the Akah river, a tributary of the Baram river in the 4th Division of Sarawak, during a short period of secondment to the World Health Organisation (June–August 1953). Two full months were spent in and around the Kayan longhouse at Long Tebangan, the primary aim being to determine the malaria vector species of the area and to examine such aspects of their biology as might affect the work of the W.H.O.-assisted Malaria Pilot Project operating on the Baram river. This paper deals only with the systematics and biology of the species found.

Dwelling Places, etc., on the Akah River.

Most observations were made in or near the Kayan longhouse at Long Tebangan, a typical village of three semi-separate houses totalling some 40 doors, set on the banks of the Akah river. The houses conform to the usual longhouse pattern, with a full length gallery or verandah along one side, and the remainder divided into individual family rooms; these are again sub-divided into a number of sleeping cubicles and a main living space. Walls and floors are of adzed planks, the roof of wooden shingles, and the whole structure is raised some five feet from ground level on massive piles. The space beneath the house is the domain of numerous domestic pigs and chickens, not to mention an unwholesome fauna of spiders, centipedes, fleas, etc. Apart from dogs and cats, no other livestock is kept.

Affiliated with the longhouse is a number of farm-houses (sulaps), built some distance away on cultivated areas and used for temporary accommodation during agricultural operations. These vary in size and construction but are all small structures of planks or palm thatch, raised on piles above the ground and generally more open and fragile than the parent longhouse. A few are occupied more or less permanently and these tend to be more solidly constructed with a scavenging squad of pigs and chickens beneath.

An even more primitive structure, also referred to as a sulap, is the normal dwelling place of the local Punans, jungle nomads of no fixed abode. These "gentle, wary wayfarers" construct rough jungle shelters, consisting of little more than a lean-to roof of bark or leaves, above a floor of parallel poles, some five feet by six feet in area and raised some two feet above the ground. They keep no domestic livestock except their dogs, and their camps are always located within the jungle, never on open ground. In other areas, such as Long Tap, the Punans are tending to settle and follow the ways of their neighbours.

Systematics.

The first problems encountered were taxonomic, since the Anopheline fauna showed some striking differences from that of North Borneo. The species found are listed below; "L" and "A" indicate whether taken as larvae or adults.

<i>Anopheles (Anopheles) aitkenii</i> James 1903	...	...	...	L.
<i>A. (A.) aitkenii borneensis</i> McArthur 1949	...	...	...	L.
<i>A. (A.) barbirostris</i> Wulp 1884	...	...	...	L.A.

<i>A. (A.) barumbrosus</i> Strickl. & Chowd. 1927	...	...	A.
<i>A. (A.) roperi</i> Reid 1950	...	...	L.
<i>A. (Myzomyia) leucosphyrus</i> group *			
<i>A. (M.) leucosphyrus leucosphyrus</i> Dön. 1901	...	...	L.A.
<i>A. (M.) pujutensis</i> Colless 1948	...	...	L.
<i>A. (M.) riparis</i> King & Baisas 1936	...	...	L.
<i>A. (M.) hackeri</i> Edw. 1921	...	...	L.
<i>A. (M.) tessellatus</i> Theo. 1901	...	...	A.
<i>A. (M.) kochi</i> Dön. 1901	...	...	A.
<i>A. (M.) stookesi</i> Colless 1955	...	...	L.
<i>A. (M.) maculatus</i> Theo. 1901	...	...	L.A.
<i>A. (M.) karwari</i> (James) 1901	...	...	L.

The most interesting feature of this list is the presence of four members of the *leucosphyrus* group, two of them (the type form and *A. riparis*) not before recorded from Borneo. The occurrence of *A. l. leucosphyrus* as a vector on the Akah river (J. de Zulueta & D. H. Colless, unpublished) is particularly interesting since the writer's investigations in North Borneo have shown that the vector there is the closely-related *A. l. balabacensis* Baisas; the type form was never found there and had been assumed to be absent from Sarawak also. The relationship between these two forms is still under investigation, but they do differ taxonomically and after some experience can be identified as both adults and larvae; keys for their separation will be published in the near future. But little, if any, biological difference has been detected as yet and it is not clear whether they are geographic subspecies or incompletely differentiated species. It does, however, seem necessary to distinguish the two forms, for the present at least.

A further point of interest is the re-discovery of *A. stookesi*, a rare tree-hole breeder, hitherto known only from Tambunan, North Borneo.

Mosquito Biology.

Biological investigations were largely concerned with the feeding and resting habits of *A. l. leucosphyrus*—other species were so uncommon that little can be

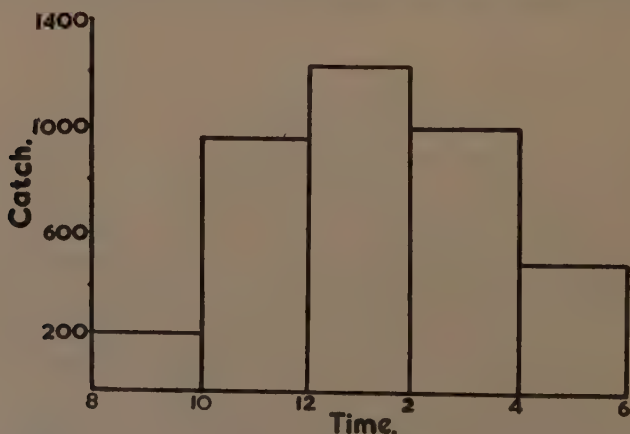


Fig. 1.—Total catch of *A. l. leucosphyrus*, by 2-hourly periods (8 p.m. to 6 a.m.).

* Throughout this paper the status accorded to the members of the *leucosphyrus* group, previously regarded as varieties or subspecies, is based on a detailed review of the group to be published in the near future. In particular, the reasons for regarding *A. pujutensis*, *A. riparis* and *A. hackeri* as good species are clear-cut morphological differences and sympatric distributions.

said of them. Results were obtained principally from catches made by night in the Long Tebangan house by a team of five locally-recruited assistants, each man working for two hours of the night, searching walls, beams, sleeping occupants, etc., by the light of an electric torch, and collecting all resting or feeding mosquitos in marked test tubes. A natural reluctance to disturb the occupants of the house, together with a plentiful supply of resting mosquitos, made captures during the act of biting rather rare, but as the search was continuous, it was assumed that mosquitos found resting in the engorged condition had fed only a short time previously. The catchers operated in nightly rotation to eliminate individual differences in efficiency, and each catch was classified according to species, time of capture (by 2-hour periods), condition (fed, unfed, or biting), and height of resting place. For the latter, three arbitrary zones were defined, from floor level to 3 ft., from 3 to 5 ft., and above 5 ft.

Further catches were made in farm-houses and Punan sulaps. Similar methods were used but, in the former, height of resting place was not recorded and, in the latter, only species and time of capture were noted. Other miscellaneous observations were also made in various places as described below.

Feeding and resting habits of A. l. leucosphyrus.

As shown in Tables I-IV and fig. 1, feeding-activity is spread over the whole night, but most takes place in the early hours of the morning—32 per cent. of

TABLE I.

Catches of *A. l. leucosphyrus*, Long Tebangan house.
(28 nights, 280 man/hours)

Period		8 – 10 p.m.	10 – mnt.	mnt. – 2 a.m.	2 – 4 a.m.	4 – 6 a.m.	Total
Biting		8	8	8	2	3	29
Resting, up to 3'	Unfed	49	77	46	16	5	193
	Fed	34	353	502	370	200	1459
	Total	83	430	548	386	205	1652
Resting, 3' to 5'	Unfed	12	46	23	6	5	92
	Fed	23	159	249	253	132	816
	Total	35	205	272	259	137	908
Resting, above 5'	Unfed	5	10	0	2	0	17
	Fed	2	34	20	23	8	87
	Total	7	44	20	25	8	104
Total resting	Unfed	66	133	69	24	10	302
	Fed	59	546	771	646	340	2362
Grand total (biting and resting)		133	687	848	672	353	2693

Other species: *A. barbirostris* -- 54
A. maculatus -- 20
A. tessellatus -- 5

the catch was taken between midnight and 2 a.m., and 82 per cent. between 10 p.m. and 4 a.m. Individual nights showed some variations, with peaks as early as the 10 p.m.-midnight period or, on one occasion, as late as 4-6 a.m. and there is evidence that during wet weather the peak of entry tends to fall in the 10 p.m.-midnight period (see below).

TABLE II.

Catches of *A. l. leucosphyrus*, Long Siniei & Long Tap (longhouses).
(3 nights, 30 man/hours)

Period		8 - 10 p.m.	10 - mnt.	mnt. - 2 a.m.	2 - 4 a.m.	4 - 6 a.m.	Total
Biting		0	0	1	1	0	2
Resting, up to 3'	Unfed	13	15	4	1	1	34
	Fed	29	45	68	57	23	222
	Total	42	60	72	58	24	256
Resting, 3' to 5'	Unfed	0	1	1	0	0	2
	Fed	1	9	39	21	48	118
	Total	1	10	40	21	48	120
Resting, above 5'	Unfed	0	0	1	1	0	2
	Fed	0	1	11	0	0	12
	Total	0	1	12	1	0	14
Total resting	Unfed	13	16	6	2	1	38
	Fed	30	55	118	78	71	352
Grand total (biting and resting)		43	71	125	81	72	392

Other species: *A. barbirostris* — 23
A. maculatus — 7

On first entering the house a proportion of the mosquitos rests on the walls before feeding, and probably all do so after feeding. No attempt was made accurately to estimate the length of resting periods, but a few individual observations of fed mosquitos (8 only) showed periods from 2 to 38 minutes, average 12 minutes. Both fed and unfed mosquitos tended to rest low down on the walls—62 per cent. were taken below 3 ft., and 96 per cent. below 5 ft. Of the 4 per cent. taken above 5 ft., practically none were taken above 6 ft.; this result was possibly influenced by the difficulty of catching high-resting mosquitos, but the bias, if any, was small and the figures given are a good estimate of the actual distribution.

In spite of the tendency of the mosquitos to rest in the house, all but a negligible percentage leave before daybreak. On two occasions, during periods of large catches, no catch was made during the night, but the house was thoroughly searched at 8 a.m. on the following day. Fifteen man/hours so spent produced only one *A. barbirostris* and two *A. l. leucosphyrus*, the latter in a small and

extremely dark cubicle. Thus *A. l. leucosphyrus* resembles *A. l. balabacensis* in its almost complete aversion to day-time resting in houses. Since feeding does not cease until dawn is well-advanced, it is in fact surprising that more are not trapped in the house by the advancing day.

Observations made outside the house throw further light on the movements of the mosquitos. From about 7.30 p.m. onwards, unfed females of *A. l. leucosphyrus* could be found resting on posts, foliage, etc. around the house,

TABLE III.

Catches of *A. l. leucosphyrus*, Long Bahang & S. Makoti (farms).
(2 nights, 20 man/hours)

Period		8 – 10 p.m.	10 – mnt.	mnt. – 2 a.m.	2 – 4 a.m.	4 – 6 a.m.	Total
Biting		8	40	21	20	5	94
Resting	Unfed	3	23	7	2	2	37
	Fed	0	42	56	46	22	166
Total		11	105	84	68	29	297

Other species: *A. barbirostris* — 7
A. maculatus — 1

particularly when concentrated around small farm-houses. On two such occasions, at different farms, some 15 to 20 were seen resting together on the leaves of a single small tree. It was noticeable that although they could be found scattered all round the house, most were concentrated on the one tree (papaya in one case, and rubber in the other), which was close against the house, with its upper branches at floor level. Over a period of some 2 hours they slowly disappeared, presumably into the house, but in both places single mosquitos were seen to remain for over 1½ hours. Apparently the mosquitos emerged from their resting places early in the night but spent a quite long period close to the house before entering to feed. Moreover, the small trees mentioned appeared to provide a most favourable route for entry.

TABLE IV.

Catches of *A. l. leucosphyrus*, Punan sulaps.
(3 nights, 54 man/hours)

Period	8 – 10 p.m.	10 – mnt.	mnt. – 2 a.m.	2 – 4 a.m.	4 – 6 a.m.	Total
Catch	16	82	174	159	32	463

Other species: *A. barbirostris* — 65
A. barbumbrosus — 5
A. maculatus — 7
A. tessellatus — 3

A point of some importance is whether females of *A. l. leucosphyrus* rest beneath the houses. On six occasions, at different hours of the night, one-hour searches were made beneath farm-houses and longhouses, while large numbers

were being taken in the rooms above and, at the farms, while numerous unfed females were resting on bushes, etc. near the house. A few *A. maculatus* and *A. tessellatus* were taken near sleeping pigs, but only one *A. l. leucosphyrus*, resting on the undersurface of the flooring. It appeared that *A. l. leucosphyrus* was entering and leaving the houses through windows and other openings in the walls and that very few came up through, or rested beneath, the floor. Furthermore, search around sleeping pigs, dogs and chickens indicated that such bait was unattractive to this species, thereby removing a possible reason for entry below the house.

A further point of interest is found in Tables I and II, if the percentage of mosquitos taken in the unfed condition is calculated for successive periods of the night, as follows:—

Period		8-10 p.m.	10-mnt.	mnt.-2 a.m.	2-4 a.m.	4-6 a.m.
Percentage unfed {	Table I	52.8	19.6	8.2	3.6	2.9
	Table II	30.2	22.5	4.8	2.5	1.4

This percentage will depend not only on the proportion which rest before feeding, but also on the length of the resting period. It may be treated as the "amount" of resting, a population index inversely proportional to the readiness of the mosquitos to feed immediately upon entering. The regular decrease through the night (fig. 2) is quite striking; over the first four periods the graph

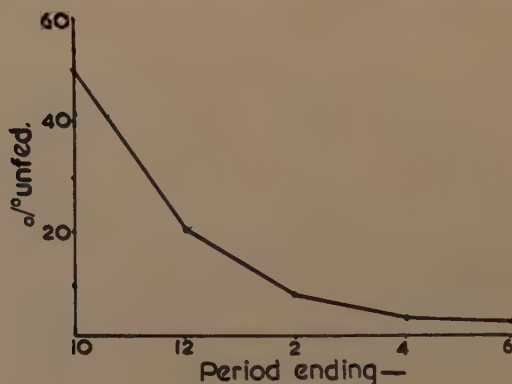


Fig. 2.—Percentage of *A. l. leucosphyrus* taken unfed, by 2-hourly periods (10 p.m. to 6 a.m.).

is almost perfectly exponential, though the significance, if any, of this fact is not clear. In popular terms, one may say that the later the mosquitos arrive, the hungrier they are, which seems not unnatural. In terms of stimulus and response, it seems that two separate stimuli, or levels of activation, are needed; one to produce movements which bring the mosquito to the bait, and another to initiate the act of feeding. Early arrivals tend to be incompletely activated with regard to the latter but later in the night the cumulative effects of stimuli received outside the house tend to promote immediate feeding. The observed tendency to rest outside, near the house, supports this hypothesis.

Effects of climatic variation.

Fortunately the two-month period of the survey was quite sharply divided into three approximately equal periods of differing climate. Period 1 was extremely dry and almost rainless but changed abruptly to Period 2, of wet weather with heavy rain almost daily. In Period 3 there was a fairly sharp

change back to dry weather with occasional storms. If the 28 night-catches from Long Tebangan house are assigned to these three periods (12, 8 and 8 nights respectively) as in Tables V and VI, certain variations can be seen which are presumably correlated with weather conditions.

In Table V it can be seen that catches were much higher during the wet weather of Period 2 than in the dry periods. The close association between the increase in catch and the onset of heavy rain suggested that the increase was

TABLE V.

Catches of *A. l. leucosphyrus*, Long Tebangan house, by climatic periods.

Period		1	2	3
Biting		15	12	2
Resting	Unfed	34	194	74
	Fed	707	1002	653
	Total	741	1196	727
Grand total		756	1208	729
Catch/man/hour		6.3	15.1	9.1
% resting unfed		4.6	16.2	10.2

not due to increased breeding, and it seems possible that the population was immediately increased by the favourable effect on adult survival of higher humidities, particularly in day-time resting places. The writer has published evidence suggesting such an effect on the closely related *A. l. balabacensis* (Colless, 1952). That the increase in catch was an effect of humidity near the ground is supported by the abrupt rise in catches between Periods 1 and 2, as compared with the gradual fall during about the first week of Period 3.

However, it must be noted that the proportion taken unfed also rose during Period 2. It seems probable that this reflects an increase in the average period of rest before feeding, which, with the catching technique described, would result in a greater proportion being taken while unfed. However, the period of rest after feeding may also have been increased. This period is normally much longer than that before feeding, and any increase would thus have a relatively smaller effect upon the catch. If the observed increase in the proportion taken unfed reflects any such general tendency to longer resting, the increased catch in Period 2 may have been due, in part at least, to the consequent increase in probability of capture. It is a fact that, over the 28 nights, the percentage of unfed mosquitos was closely correlated with total catch ($r = +0.72$), tending to support the latter view. For nights within periods, a similar correlation is found in Period 2 ($r = +0.81$), though not within Periods 1 and 3.

Whatever the explanation, it appears that, during the wet period, mosquitos did tend to rest before feeding to a greater extent than during the dry periods. Possibly atmospheric conditions during wet weather stimulate an earlier approach to the bait, but on arrival many mosquitos are insufficiently activated for immediate feeding. Such an explanation is supported by the figures in Table VI which show that during Period 2 the peak of entry was at least one hour earlier than during Periods 1 and 3. Taken together, both facts support

the hypothesis mentioned above of two separate stimuli, one promoting arrival at the bait and the other the act of feeding.

Breeding places.

Little time was available for larval surveys, but a number of breeding places were located near the longhouse. *A. l. leucosphyrus* and *A. pujutensis* were taken in large numbers in small pools beside a jungle stream and in swampy patches along the hill foot; most pools were well shaded but some received at

TABLE VI.

Catches of *A. l. leucosphyrus*, Long Tebangan house, by climatic periods.

Period	8 - 10 p.m.	10 - mnt.	mnt. - 2 a.m.	2 - 4 a.m.	4 - 6 a.m.
1	23	156	282	208	87
2	86	378	359	260	125
3	24	153	207	204	141

least one hour's sunlight daily. The aptly-named *A. riparis* was however taken only along jungle streams, and *A. hackeri*, on one occasion only, in a rotting stump at the foot of the longhouse steps. Other species were all found in typical situations—*A. maculatus* mainly in river gravels, *A. barbirostris* in stagnant pools and river gravels, *A. karwari* in open seepages, *A. a. borneensis* in rocky jungle seepages, *A. aitkenii* in shaded seepage swamp, and *A. stookesi* in a tree hole.

Summary.

Investigations on the Akah river, in the 4th Division of Sarawak, showed 13 species and one variety of *Anopheles* to be present. *A. l. leucosphyrus* Dön., the principal malaria vector, was the only species common in houses.

A. l. leucosphyrus has a strong preference for human blood and feeds throughout the night, with a peak of activity soon after midnight. Both fed and unfed mosquitos rest indoors on the walls but the latter become increasingly scarcer later in the night. Most individuals rest low down (62% below 3 ft., 96% below 5 ft.) but only a negligible percentage remains in the house after daybreak. Observations suggest that many females spend quite long periods resting outside the house before entering and that entry is almost entirely through windows and other openings in the walls; very few enter the space below the house. There is also evidence of two separate stimuli, or levels of activation, one bringing the mosquito to the bait and one initiating the act of feeding.

Wet weather was accompanied by an abrupt increase in catches of *A. l. leucosphyrus* and dry weather by a decrease—this is thought not to be due to any effect on breeding places. During the wet period, females entered earlier and tended to rest to a greater extent before feeding.

Acknowledgements.

It is a pleasure to acknowledge here my indebtedness to the Regional Director, Western Pacific Region, World Health Organisation, for the opportunity to carry out this work and permission to publish the results, and to the W.H.O. Senior Malaria Adviser, Dr. Julian de Zulueta, for considerable

assistance and advice in organising and planning the work; also to my assistants, Sidop bin Suleiman. Michael Tan, and the locally-recruited Kayans, who were jointly responsible for the more tedious phases of the work; to the Rev. & Mrs. Southwell and other members of the Borneo Evangelical Mission for much hospitality and a most enjoyable plane trip back to the coast; and last but not least, to Jok Ngau, headman of Long Tebangan house, and many other Kayan, Kenyah and Punan residents of the area, for hospitality and cheerful co-operation.

References.

- COLLESS, D. H. (1952). Observations on the periodicity of natural infections in the Anopheline mosquitoes of Borneo.—*Med. J. Malaya*, **6**, pp. 234–240.
- COLLESS, D. H. (1955). New Anopheline mosquitoes from North Borneo.—*Sarawak Mus. J.*, **6**, pp. 331–342.
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MOSQUITO POPULATIONS AT IBADAN IN NIGERIA.

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The experiments described in this paper were carried out from March 1951 to May 1953. They were part of a survey of the permanent site of the University College at Ibadan in Nigeria. Ibadan is situated $7^{\circ}26' \text{ N.}$ and $3^{\circ}54' \text{ E.}$, about 100 miles inland from the sea, and at a height of between 650 and 900 feet above sea level. The University College is located some four miles to the north of the town, on its own large site of some 2,000 acres. Until 1950 the site was quite undeveloped. Most of it was what is often, very inaccurately, described as "virgin bush". Only a small proportion of the area was at any time covered with growing crops (yams, maize, cassava) and the rest was left as a bush fallow for from seven to ten years. During that period the trees regenerated, some reaching more than 20 ft., and except where narrow tortuous paths existed the thicket was almost impenetrable. Permanent crops existed to some extent. There were a few small patches of cacao, and a number of scattered oil palms.

Building work was begun in a small way in 1949, but the major construction did not start until January 1951. By May 1953, when the experiment ended, about 100 houses for senior staff, several hundred houses for servants and junior employees, and the major part of the College buildings proper, including four

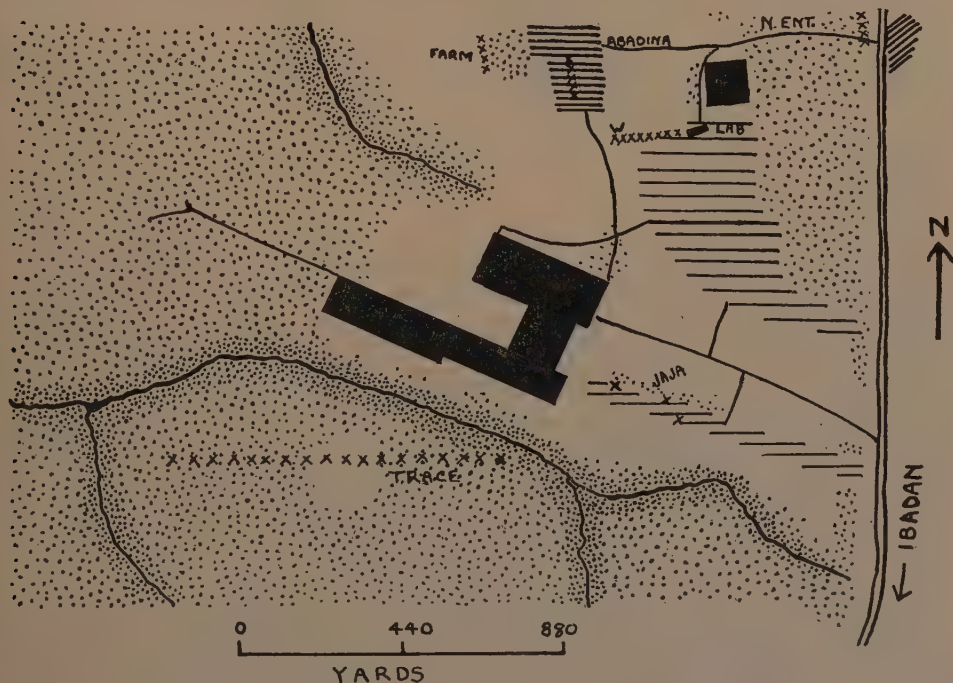


Fig. 1.—Sketch map of the site of University College, Ibadan, Nigeria.
For explanation see text.

* Now at Rothamsted Experimental Station.

halls of residence, arts block, administrative building and laboratories had been completed or were nearing completion. As noted below, collections were made in various different localities, some where housing had been constructed and some where the bush remained untouched.

The work was planned originally to see how the development of the site, and attempts at the control of the insects on it, affected the population of mosquitos. The effects of the annual climatic cycle on the insects were also noted. As is usual in experimental work, the points originally considered most likely of solution proved most difficult to elucidate, and the results obtained relate to other aspects of the problem.

The part of the site used in these experiments is shown in fig. 1. The major part, indicated by widely spaced dots, was not cleared during the period under consideration, and was mostly well established "bush fallow". Denser bush along the watercourses is shown by closer stippling. The white areas were cleared of bush before this work started and were either kept cleared or used to grow crops (*e.g.*, maize) so they remained reasonably clear. Areas of housing are illustrated by horizontal lines. Those close together show Abadina village, where junior employees of the College (all Africans) were housed in modern dwellings but at a fairly high density. The areas where academic staff (mostly European) were housed are shown by more widely spaced horizontal lines; here the maximum density was one house to an acre, but servants' quarters doubled this, and meant that about as many Africans as Europeans occupied the area. In this it differed from most "European" housing areas in West Africa, where servants and their families may outnumber by as much as ten to one their employers. Most servants with families on the College site lived in Abadina village, and single men occupied the houses in the senior residential area. The College buildings proper are shown in black. Those in the north-east corner were constructed before the experiment started. Work did not start on those in the centre, which formed the main part of the College, until early in 1951; the southern range of buildings did not start until towards the end of the experimental period. More details of the various areas are included in subsequent sections of this paper.

Technique.

Pots containing water were exposed in various positions, and mosquito larvae which developed from eggs laid in the pots were collected and identified.

The containers used were locally made earthenware pots, 12" high with a diameter of 10" at the top and of 12" at the widest part. They were filled between half and two-thirds full of water. Every five days (or six days if the fifth day was a Sunday) the pots were examined. The water was passed through a strainer made of fine mosquito netting with 18 by 24 holes per square inch. The débris left on the strainer was then carefully washed off into a numbered jar, and counted and sorted on return to the laboratory. Seventy pots were used, and the collections proceeded for more than two years, during which period more than 10,000 individual pot collections were made. Those recorded here cover the period April 1951 to May 1953.

The following species of larvae were recorded separately:—

Anopheles (Myzomyia) gambiae Giles

Aedes (Stegomyia) aegypti (L.)

Culex (Lutzia) tigripes Grp.

In addition the following species were commonly found:—

Aedes (Stegomyia) vittatus (Big.)

Culex (Culex) decens Theo.

Culex (Culex) duttoni Theo.

The records for these, together with smaller numbers of other species, some of which were not identified further, were lumped together as "miscellaneous Culicines".

Life other than mosquito larvae was found in the pots from time to time. Chironomid larvae were common, and dragonfly larvae and toad tadpoles occurred in many pots. Although the occurrence of these was not studied closely, it was evident that the tadpoles were found mostly in March and April, *i.e.*, in the earlier part of the rainy season, and the dragonfly larvae in May and June.

Areas surveyed.

The 70 pots used in these experiments were divided into six groups, which were placed in six different parts of the site (see fig. 1). The positions of the six groups are described below.

Ja Ja Avenue.—The first group of bungalows built for members of the academic staff of the College was situated along a road later named Ja Ja Avenue. These houses were completed in 1950. Each house was situated in a compound of about one acre, but most of the householders found this too much to keep cultivated and an area resembling the "bush fallow" mentioned in the introduction sprang up between the gardens. Nine pots, in three groups of three, with ten yards between the pots in each group, were placed in these somewhat overgrown patches; about 200 yards separated each group from the next. The pots were all within 50 yards of staff houses, and of the separate blocks of servants' quarters. About 400 yards south of the houses there was a small stream with unfelled trees fringing it, otherwise the area surrounding Ja Ja Avenue was cleared and mostly used for crops of maize, etc.

Farm.—The first temporary farm buildings were erected by the Department of Agriculture of the College in 1950. Some twenty cattle and a few horses were housed in these buildings which were built of concrete with aluminium sheet roofs, or of timber with thatched roofs. The buildings were not screened. A patch of unfelled bush containing some tall trees separated the farm from Abadina village (see below). Six pots were placed in a row, 20 yards apart, and within 20 yards of the cattle sheds. The pots were shaded for part of the day.

The cattle were in the sheds at night and during the hottest part of the afternoon.

North Entrance.—When the site was acquired, a rough road along which a lorry could be driven in dry weather entered at this point, and proceeded some distance to outcrops of rock which were quarried. To the south of the entrance the bush was not cleared during the course of the experiment, but to the north an area of teak was planted as an eventual supply of firewood for the College. The main Ibadan-Oyo road formed the eastern border of the site. Immediately opposite the entrance there was a small village occupied, when a census was taken in 1953, by 43 Africans living in thatched mud huts (one hut had a corrugated iron roof fitted in 1952). The village was surrounded by trees and uncleared bush on the side away from the road. Nine pots were placed in a row ten yards apart and about 40 yards from the village. The pots were in light shade.

West from Laboratory.—Eighteen pots were placed in a line running approximately east and west on the northern edge of the main area containing houses for the academic staff. The pots were in grass which was cut several times during the wet season, but which reached several feet high between cuttings. The line of pots was 205 yards long, and the pots were about 12 yards apart except that where a road intersected the line in the middle there was a gap of 31 yards. The average distance of the pots from houses was 50 yards.

Trace.—This was the area least affected by building operations. A surveyors' trace approximately one yard wide was cut through the vegetation near the southern boundary of the site. At one end the trace was within a quarter of a mile of the housing in Ja Ja Avenue. During the second year of the experiment, laboratories were constructed about a quarter of a mile away, but no-one resided in the area. The nearest village off the site was about three-quarters of a mile from the nearest pot. Eighteen pots were set out at 80-yard intervals on a line 1,200 yards long. Starting at the end nearest to Ja Ja Avenue, the first four were in light shade, the next five were in a clearing, and the remainder were in rather dense bush with fairly heavy shade.

Abadina Village.—This village was constructed by the College on the site of an old village of the same name. The old village houses were of mud and thatch; they were completely demolished. The new houses were all roofed with corrugated aluminium, and were built either of concrete blocks or of landcrete walls on a concrete base. Running water and electricity were supplied to the tenants. The village contained about 100 houses at the start of the experiment and 200 at the end. Ten pots were spaced at ten-yard intervals along a road

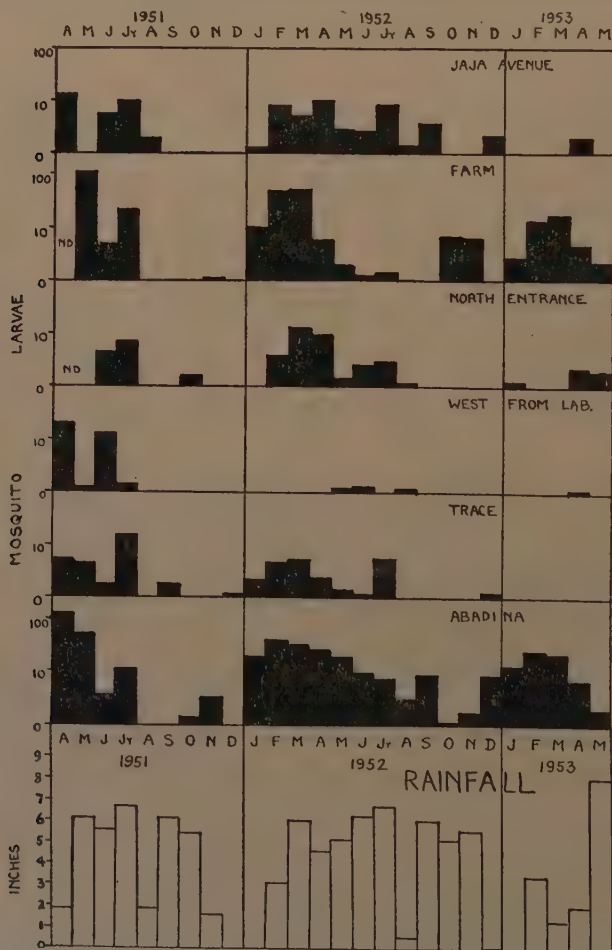


Fig. 2.—The incidence of *Anopheles gambiae* on the site of University College, Ibadan. Total monthly rainfall figures also included.

in the middle of the village; the pots were within ten yards of houses, and were in direct sunlight for a large part of each day.

Results.

In this section the figures obtained are described briefly. In the discussion (see p. 133) an attempt to explain the results is made.

The results of the examinations of the pots are shown in figs. 2-5. The graphs show, for each month, the average collection of each mosquito expressed as the "average per pot per visit" and ordinates are on a logarithmic scale. It should be noted that the results are given from April (some later) 1951 and not from January; so care must be taken in assessing the results year by year.

Anopheles gambiae.

This species occurred in the pots in all areas. The numbers are rather irregular, but they show a significant fall as the wet season progresses and a rise during the dry season. It appears that there was little change in the catch in the Farm and Abadina areas, while the catch decreased substantially in the four other habitats. It is difficult to explain the fall in these four habitats, in terms of changes in the environment. The Trace and the North Entrance were well

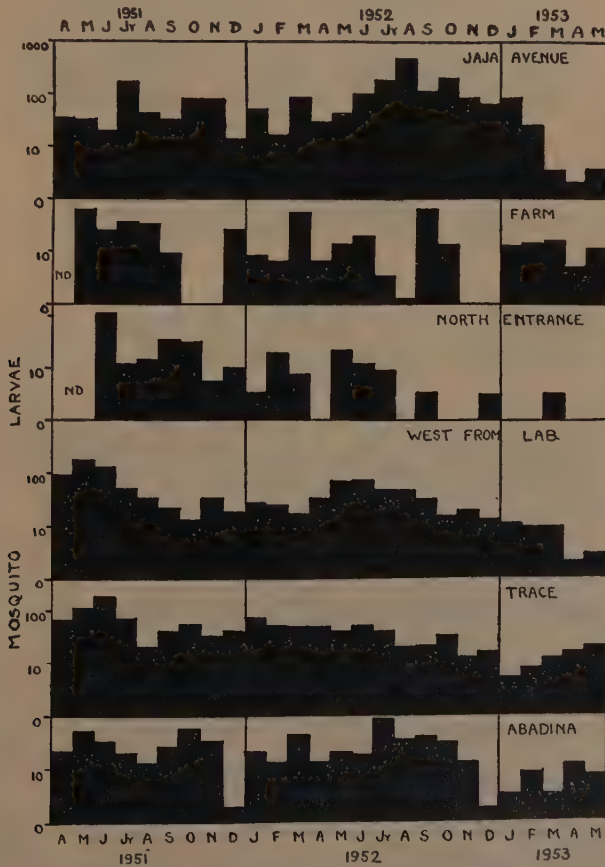


Fig. 3.—The incidence of *Aedes aegypti*.

away from the senior staff houses and no considerable change in vegetation or land usage took place. Ja Ja Avenue and the region designated "west from laboratory" were senior staff housing areas, where control measures might have been effective. Abadina was a junior staff residential area, the Farm was adjacent and might be expected to give parallel results. However, as will be seen from the discussion, it may be unwise to assume too close a correlation between these results and the fluctuations of wild populations of mosquitos which were sampled.

Aedes aegypti.

Aë. aegypti was by far the commonest mosquito whose larvae were found in the pots. This species, unlike *A. gambiae* occurs somewhat more frequently in the wet season and was least commonly found during the dry season. It occurred

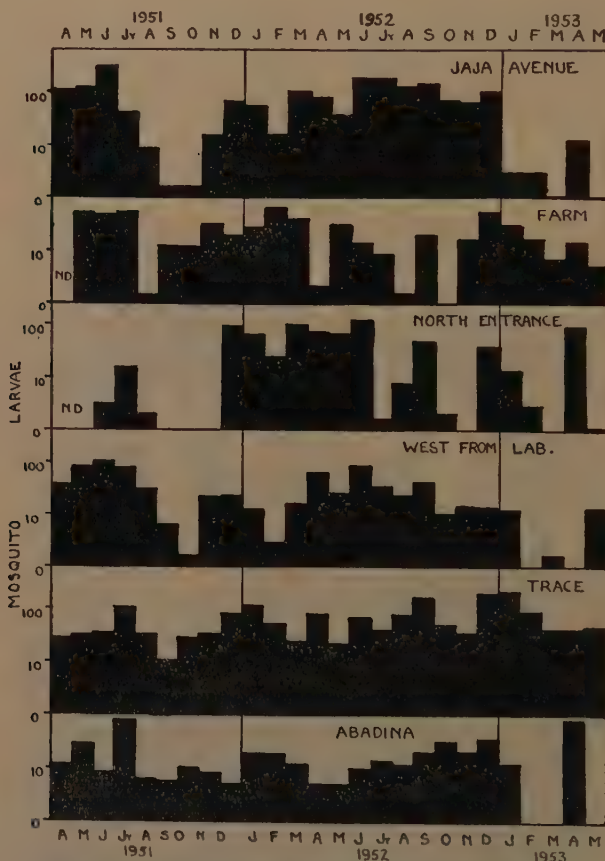


Fig. 4.—The incidence of miscellaneous Culicine mosquitos.

very commonly in the senior residential area where the *Anopheles* was comparatively rare. It also occurred frequently in the Trace even in pots which were three-quarters of a mile from the nearest habitation either on or off the site.

Miscellaneous Culicines.

These results are somewhat similar to those for *Aë. aegypti*, but, as might be expected from this miscellaneous collection, the figures are rather irregular.

Some further analysis of results from the different species does not seem to be significant, and as I am not certain that these species were always accurately determined during one period of experiment, I do not think it worth taking the matter further.

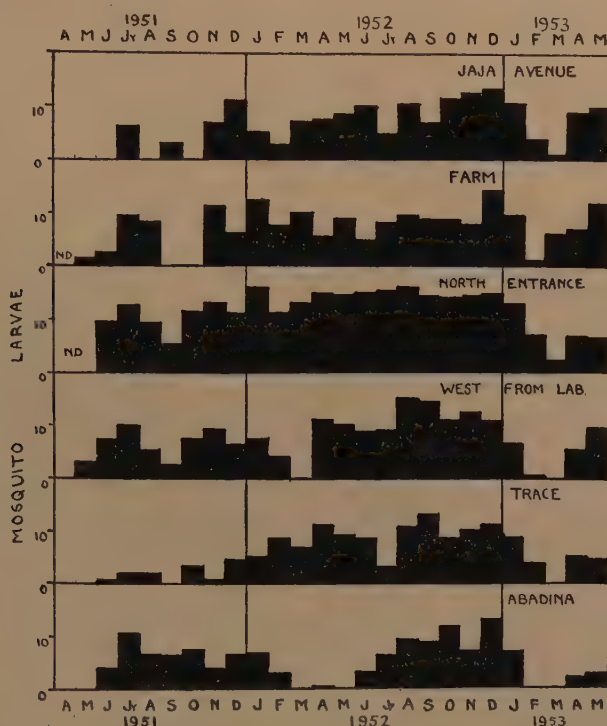


Fig. 5.—The incidence of *Lutzia tigripes*.

Lutzia tigripes.

This species became more common as the experiment proceeded. This increase might be correlated with the fall in *Anopheles*, were it not that *Lutzia* seldom eat this species but prefer *Aë. aegypti* which showed no such decrease (Jackson, 1953). The *Lutzia*, like *Aëdes* and the Culicines, increased in frequency with the wet season and decreased in the dry.

Climatic Factors.

The factor which appears to have most effect on animal and plant life in the Ibadan area is the rainfall. The figures for monthly precipitation in fig. 2 and Table I need some explanation to give a clear picture, and statements on the climate by other workers also need some amplification. In the years in which the experiments under consideration took place there was clearly a dry season which was most marked in December and January, when little or no rain fell. Average figures for a period of 47 years show a similar pattern.

Rainfall at Ibadan (inches).

Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.4	0.9	3.4	5.4	5.9	7.4	6.3	3.4	7.0	6.1	1.7	0.4

Average monthly figures over a period of 47 years to 1953. (Average total 48.3.)

In the years 1951-53 it appears that there was unusually heavy rain in February and March and the dry spell which commonly occurs in August was longer (particularly in 1952) than usual.

These figures can be misleading. Even with a considerable total rainfall, which reached 6 inches, in March 1952, the weather was quite different for

TABLE I.

Meteorological Observations, Ibadan.

	Abs. Max.	Abs. Min.	0900 Mean Max.	1800 Mean Max.	1900 Mean Min.	1900 Mean Min.	Rain- fall (ins.)	No. of days when rain recorded
April 1951 ..	98	65	84.1	93.3	72.3	80.2	1.92	8
May ..	93	67	81.1	87.0	71.0	76.9	6.06	15
June ..	90	67	79.6	86.6	71.0	76.3	5.59	13
July ..	89	66	77.5	83.5	70.1	74.7	6.63	10
Aug. ..	85	68	76.2	80.9	69.7	73.5	1.96	12
Sept. ..	88	69	77.6	84.5	71.0	74.5	6.13	17
Oct. ..	87	67	78.2	84.6	70.7	74.4	5.43	16
Nov. ..	92	61	80.1	88.3	70.3	77.2	1.57	3
Dec. ..	94	58	81	92	64	76	—	—
Jan. 1952 ..	93	52	83.1	91.0	69.0	77.6	—	—
Feb. ..	99	58	86.2	93.2	71.1	78.0	3.09	4
March ..	96	67	83.5	91.5	72.9	79.0	6.04	5
April ..	93	69	83.3	90.1	72.1	78.7	4.6	6
May ..	91	66	81.1	87.4	70.9	76.6	5.15	16
June ..	89	68	78.9	85.7	70.0	75.0	6.32	19
July ..	87	68	76.0	82.2	70.2	73.1	6.84	19
Aug. ..	86	65	76.0	81.6	69.0	72.3	0.66	9
Sept. ..	88	66	77.3	83.3	70.1	73.9	6.05	22
Oct. ..	88	67	78.3	85.2	70.4	74.5	5.08	19
Nov. ..	90	65	80.3	87.4	71.0	76.4	5.62	5
Dec. ..	91	66	80.1	87.8	70.8	76.1	0.01	1
Jan. 1953 ..	94	68	84.3	90.9	73.3	78.2	0.02	4
Feb. ..	98	58	84.4	92.3	71.9	77.2	3.45	4
March ..	99	68	84.5	91.9	72.5	78.3	1.32	6
April ..	98	68	{ 92*		{ 73†		2.10	8
May ..	93	69	{ 88*		{ 71†		8.08	15

* Mean max.
0900-0900
next day.

† Mean min.
0900 previous
day to 0900
same day.

September in the same year, although the same total rainfall occurred. In March, rain fell on five days only, and the total period of rain was only a few hours. In September it rained on 22 days and the rain fell much more gently than early in the year. The rate of evaporation was much greater in March than in September.

It is common to speak of southern Nigeria having two rainy periods, a "main" wet season from April to July, and a "lesser" wet season in September to October. This is misleading. The short "dry" season in August is very irregular, and even if there is little actual precipitation there is often much cloud and the landscape does not become at all parched. The so-called "little rains" in September and October may not reach the same total amount as in earlier months, but these are usually the months in which rain falls most frequently and (as the ground is no longer parched) when the rain is most effective. Seasonal streams may not start to flow until August and the volume

of water which flows depends almost entirely on the rainfall during the later months of the wet season.

The records show that temperatures lethal to insects seldom occur at Ibadan, and inside bushes etc. even lower maxima are found. During the dry season the greatest extremes are noted, but the range is always favourable to the species of insects under consideration. The faster rate of evaporation in the dry season probably affects temperature in water containers and so may prolong the larval period. It is probable that the effects of temperature on the behaviour of the species are more important than have so far been realised, but much more work is necessary before this can be elucidated.

Discussion.

The results shown in figs. 2-5 indicate the number of mosquito larvae of several species found in water in pots exposed in a number of habitats. Do these results tell us anything further about the mosquito population in the area surveyed?

Surveys using this type of technique have frequently been made and have given important results. Buxton & Hopkins (1927) discuss the value of such work in detail and, by taking proper precautions, they obtained much information about the occurrence and behaviour of certain species in Pacific islands. Other investigators (*e.g.*, Dunn, 1927; Harris, 1942; Hocking, 1947) have used the "Pot index" (*i.e.*, the percentage of exposed pots containing larvae of the species studied) as a measure of the incidence and their conclusions were probably justified. The experiments described in this paper show, however, that although this type of investigation can give useful results, great care must be taken when interpreting them.

Surveys of insect populations are not easy to perform if the results are to have any "absolute value" in the sense that they enable the investigator to estimate the total population of a species from which those collected in the survey form a sample. When the biology of a vector species of mosquito carrying malaria is well understood, a rapid survey of breeding places for larvae, resting places for adults and of parasite rates in the exposed human population can be of great value (*e.g.*, Leeson, 1950), but in other areas, where little is known about the vector, standard techniques are less useful, as shown by McArthur (1947) for an area in Borneo where the elusive *Anopheles leucosphyrus* Dön. appears to be the main vector. This instance indicates that an important or even the most important species in an area may be almost completely missed by sampling methods useful for other species.

The "pot" technique is clearly selective. Many species commonly found by other techniques are absent completely. But how are results obtained from species which do oviposit in pots to be interpreted?

Several surveys of *A. gambiae* in Nigeria have been made, using different techniques. Thomson (1948) collected the adult mosquitos in huts and in outside resting places. Mattingly (1949) collected the adults while they were attacking man. These authors obtained similar results. Some of Mattingly's figures are shown in fig. 6, where they are compared with the results of pot-collections at Ibadan. This diagram shows in the upper half the results of the pot-collections for Abadina village (*cf.* fig. 2) in 1952 but, to compare the rate of capture throughout the year, the figure for the month of greatest incidence (Feb.) is taken as 100, and the results are expressed as a percentage of this. The rainfall (open columns) is also shown. In Ibadan the *A. gambiae* larvae were most frequently obtained during the dry season, and decreased in numbers in the pots as the rains proceeded. Mattingly's figures (for adult mosquitos) for the Lagos area are quite different. The rainfall is not dissimilar. In the periods under

consideration the total precipitation was almost exactly the same (49.55 inches in Ibadan, 49.11 inches in Lagos) and the only major difference in distribution of rainfall is that March was wetter in Ibadan than in Lagos, and July was wetter in Lagos than Ibadan; these differences do not conceal the very similar pattern. It will be seen that up to July the mosquito population as sampled by Mattingly increased with the increasing rain, and decreased with the dry

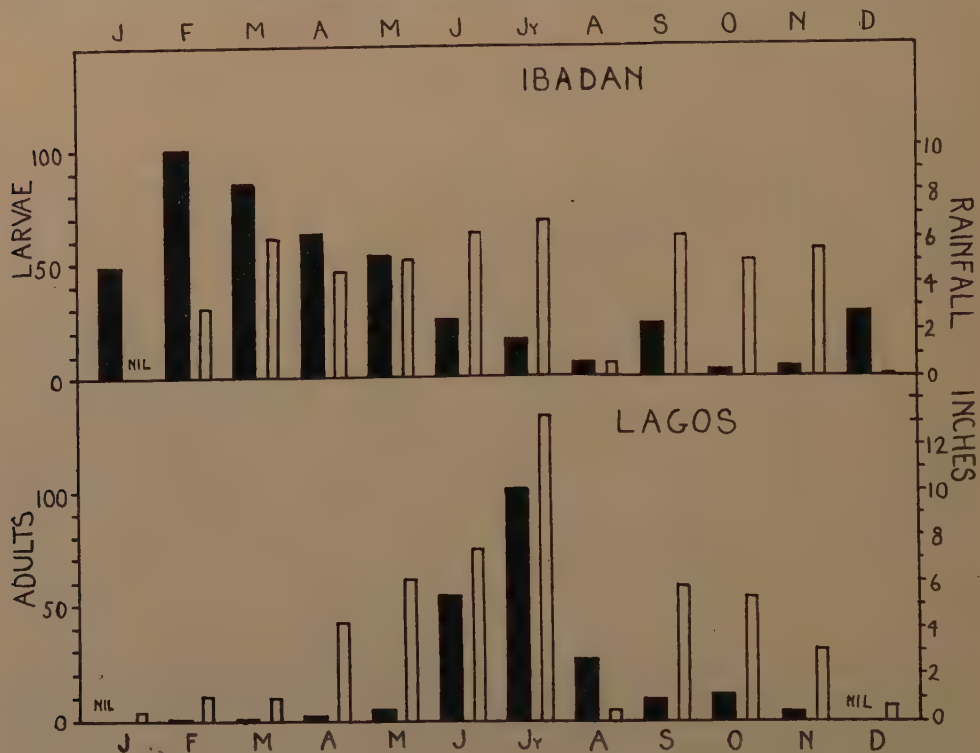


Fig. 6.—A comparison of the incidence of *Anopheles gambiae* at Ibadan and Lagos. For details see text.

weather in August. It is somewhat surprising, however, that in September and October, which were about as wet as in May and June, the mosquitos decreased even further.

The most likely explanation of the major difference of these results would appear to be that the pot results at Ibadan do *not* measure the incidence of *A. gambiae* as accurately as do the adult collections. In the dry season, this species appears to be common, because there are few alternative breeding places. In the wet season, when the adults as measured by other methods are apparently more numerous, fewer oviposit in the pots as there are many alternative places from which to choose. This may be correct, but we have no proof that Mattingly's and Thomson's results are altogether accurate assessments, and the fall in numbers found in the latter part of the rainy season makes their figures difficult to interpret. It may be that the increase in the density of the vegetation (which reaches its maximum about November) influences the choice of resting places and of behaviour generally, and that adult catches, either in houses or as the mosquitos attack their victims, are not necessarily always accurate assessments of populations. We know that the tsetse fly may have a

different distribution in the wet and in the dry season, correlated with changes in the density of the vegetation (see, Shircore, 1914; Nash, 1937) and mosquitos may well behave in a similar manner.

The results obtained with *Aë. aegypti* and with the Culicine mosquitos indicate that, on the whole, there were most larvae in the pots during the wet season, and the lowest numbers occurred in the dry season. These findings are in agreement with those of previous workers. Nevertheless without corroborative evidence, it would be unwise to assume that these figures derived from pots give in any way an accurate assessment of the total population.

Some workers may find these conclusions regarding the value of pot collections disappointing. I do not think this should be the case. Pot collections can tell us much about the biology of a species. They can elucidate points regarding egg-laying and the selection of breeding sites, about distribution, and about behaviour particularly in relation to climatic and environmental factors. Pot collections are less affected by personal and subjective factors than many other measurements of populations and the results should always be of ultimate value provided that the experimental conditions are kept as constant as possible and the details are fully recorded. The results do not at present give a complete picture of a mosquito population, but, in conjunction with other observations of different factors in the environment, they may contribute to a fuller knowledge of the mosquito problem and of the relation of the species to its environment. I believe that it is useful at this time to point out how incomplete our knowledge still is, and how uncertain may be the application of some results, in the hope that it will stimulate more intensive research on this and allied problems.

Summary.

Mosquito larvae derived from eggs laid in earthenware pots in various habitats on the site of University College, Ibadan, in Nigeria were collected over a period of 26 months.

Anopheles gambiae Giles, *Aëdes aegypti* (L.) and *Culex (Lutzia) tigripes* Grp. were the species most frequently collected.

The relation of these results to the fluctuation in the populations of the species concerned is discussed. It seems unlikely that pot collections give results which can be directly related to the numbers of mosquitos in the field, but they can elucidate questions of mosquito biology and behaviour.

Acknowledgements.

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I am indebted to the members of the staff of the Department of Parasitology of University College, Ibadan, for the part they played in the experiments, particularly to Mr. H. J. Sutton for supervising many of the pot collections and to Mrs. N. Jackson for work with the collections and for doing much of the computation of the data. The meteorological records were kindly supplied by the Director of Meteorological Services of Nigeria.

References.

- BUXTON, P. A. & HOPKINS, G. H. E. (1927). Researches in Polynesia and Melanesia. Parts I-IV.—Mem. Lond. Sch. Hyg. trop. Med., no. 1, 260 pp.

- DUNN, L. H. (1927). Mosquito breeding in "test" water-containers.—Bull. ent. Res., **18**, pp. 17–22.
- HARRIS, W. V. (1942). Notes on Culicine mosquitos in Tanganyika Territory.—Bull. ent. Res., **33**, pp. 181–193.
- HOCKING, K. S. (1947). The use of bamboo pots to indicate *Aedes* prevalence.—Bull. ent. Res., **38**, pp. 327–333.
- JACKSON, N. (1953). Observations on the feeding habits of a predacious mosquito larva, *Culex (Lutzia) tigripes* Grandpré and Charmoy (Diptera).—Proc. R. ent. Soc. Lond., (A) **28**, pp. 153–159.
- LEESON, H. S. (1950). Anopheline surveys in Syria and Lebanon 1941 to 1943.—Mem. Lond. Sch. Hyg. trop. Med., no. 7, pp. 1–46.
- MCARTHUR, J. (1947). The transmission of malaria in Borneo.—Trans. R. Soc. trop. Med. Hyg., **40**, pp. 537–558.
- MATTINGLY, P. F. (1949). Studies on West African forest mosquitos. Part I. The seasonal distribution, biting cycle and vertical distribution of four of the principal species.—Bull. ent. Res., **40**, pp. 149–168.
- NASH, T. A. M. (1937). Climate, the vital factor in the ecology of *Glossina*.—Bull. ent. Res., **28**, pp. 75–127.
- SHIRCORE, J. O. (1914). Suggestions for the limitation and destruction of *Glossina morsitans*.—Bull. ent. Res., **5**, pp. 87–90.
- THOMSON, R. C. MUIRHEAD. (1948). Studies on *Anopheles gambiae* and *A. melas* in and around Lagos.—Bull. ent. Res., **38**, pp. 527–558.
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SOME ASPECTS OF MEALYBUG BEHAVIOUR IN RELATION
TO THE EFFICIENCY OF MEASURES FOR THE CONTROL
OF VIRUS DISEASES OF CACAO IN THE GOLD COAST.

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(PLATE IV.)

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In the light of present knowledge of insect-borne virus diseases in general and those affecting cacao in particular, it is conceivable that swollen shoot disease of cacao in West Africa might be controlled by three different methods, by eradicating sources of infection, by eliminating the insect vectors, or by replacing the existing tree population with immune or highly resistant varieties.

At present, only the first of these methods is of immediate application. Experience shows that vector control to the point necessary to reduce appreciably the rate of spread of swollen shoot disease is so difficult as to be unattainable in practice (*cf.* Bawden, 1955). No new varieties sufficiently resistant to disease have yet been produced and their use in any event could not affect the immediate problem. The eradication of sources of infection, by contrast, has definitely reduced and even halted the spread of swollen shoot disease where it has been possible to apply it thoroughly and systematically (Quarterly Reports of Cocoa Division), and it seems that this method must remain the standard one for some time to come.

In the interests of efficiency, however, it is obviously necessary to examine the operation of this method in relation to the properties of the pathogen and the behaviour of the vector in order that possible refinements may be introduced. The present paper is a contribution to such examination, and reports on an investigation into the fate of mealybugs on cacao trees which are cut out in the course of control operations.

Cutting-out Operations.

In the process of "cutting out", the soil immediately around the base of an infected tree is removed and the tap root is cut below the lateral roots. Where possible, the diseased trees are felled away from those which are healthy and towards others which are infected. Until 1948, the trees were left where they were felled, but more recently the diseased trees have been formed into "slash piles" at least five paces from the nearest surrounding healthy trees. About four feet of the trunk is cut from the base of the trees and stacked at another site to form the "stump pile" to provide evidence of the number of trees cut out. The remaining trunks and heavy branches are then placed vertically around the slash pile, providing it with a conical shape and preventing the smaller leaves and twigs from being blown about by the wind (Pl. IV, fig. 1). Leaves, twigs and pods which become detached during felling are collected and placed in the slash pile, and the area around the pile is cleared of vegetation for a distance of about four paces. There is a large variation in the size of piles; in isolated outbreaks or areas of retreatment they may be small and composed of two or three trees, but in farms which are clear-felled the piles may be eight feet across the base and of a similar measurement in height.

At initial treatment only those trees showing disease symptoms are removed; isolated healthy trees and those with latent infection remain untreated. After one month, initial treatment is followed by re-inspection and, during retreatment, those trees in which latent symptoms have become apparent are cut out. Following the removal of all diseased trees, the area may be replanted.

Mealybug Populations on healthy and diseased Cacao.

The distribution of *Pseudococcus njalensis* Laing, the dominant virus vector on cacao in the Gold Coast, is markedly skew and the log ($n + 1$) transformation of Williams (1937) provides a distribution much closer to the normal than that given by the untransformed data (Strickland, 1951b). The skew "arithmetic" distribution and the more normal logarithmic distribution are applicable to the population on trees sampled from a large block of cacao (Strickland, *l.c.*), and to the population on all trees contained in a very small area (Cornwell, 1955).

To compare the distribution of mealybugs on healthy and recently infected cacao, a chi-squared test of significance was made between Strickland's data, from a tree population of which 93.6 per cent. were healthy, and data obtained from infected trees cut out about a quarter of a mile away during the period July 1951 to July 1953. Whilst the comparison made in Table I indicates a significantly lower population on the recently infected trees, which is mainly the result of numerous trees supporting no mealybugs, it must be emphasised that the two samples were taken at different times and in different localities. Significant differences have been shown by Strickland (1951b) to occur between the mealybug infestations of neighbouring plots. From numerous field observations, however, it has been noted that in swollen shoot outbreaks the mealybug population is usually low and frequently non-existent. These observations substantiate those made by the previous worker.

Results, previously unpublished, are available of an experiment carried out by R. Wickens, Agronomist of this Institute, to examine the differences which exist between mealybug populations on trees with symptoms of swollen shoot which still retain their canopy and those diseased trees, described as moribund, which retain very few leaves and are devoid of canopy. Twenty four trees were selected in pairs, "moribund" and "symptom-bearing", as close together and as similar in size as possible. The mean population values shown in Table II indicate that on moribund trees there is a reduction of adult and nymphal populations on

trunks, branches and whole trees; in the case of adult populations on trunks and whole trees this reduction is significant. Since adults are the reproductive centre of the population a reduction in adults will finally lead to a reduction in the total population.

To compare the distribution of mealybugs on various parts of healthy and recently infected trees, a comparison was made between Strickland's data (1951a)

TABLE I.

Mealybug population distribution on healthy and recently infected cacao.

Mealybug classes	Tree population 93.6% healthy (Strickland's data)		Tree population 100% infected		χ^2
	Number	%	Number	%	
0	396	62.0	672	82.4	6.72
1	17		5		
2	16		3		
3	10		2		
4 - 24	97		28		
25 - 49	84	9.7	31	3.6	3.85
50 - 99	80	9.3	30	3.5	3.61
100 - 199	69	8.0	42	4.9	1.21
200 - 399	50	5.8	30	3.5	0.92
400 - 799	29	3.4	7	0.8	1.94
800 and over	16	1.8	11	1.3	0.18
Total	864		861		18.43**

N.B. Throughout this paper the following symbols have been used to denote statistical significance:—

*** significant at $P < 0.001$;

** significant at $P < 0.01$;

* significant at $P < 0.05$.

for the distribution of *P. njalensis* on 1,180 mature trees and data obtained from 861 diseased trees. The results indicated that there was no significant difference between the distribution of feeding sites, and that those portions of the tree from which slash piles are made support 98 per cent. of the total population. The four-ft. logs, cut from the base of the trunks and from which the stump piles are made, support 2 per cent. of the mealybug population.

Factors influencing Mealybug Density.

The low mealybug population on infected trees might be caused by numerous factors contributing to reduce the palatability of the diseased host. Goodall (1949) showed that infection of cacao seedlings significantly reduced the water content of all parts of the plant, particularly the stem. To ascertain the water content of branches of healthy and symptom-bearing trees in individual tree outbreaks, trees were selected in pairs, "healthy" and "infected", as close together and as similar in size as possible. From 13 pairs a sample of 20 four-in. pieces of branch was cut randomly from the canopy of each tree. As it was known that in healthy tissues thick branches contain a slightly lower sap content than thinner wood, a preliminary analysis was made to compare the mean dry weights of the samples. There was no significant difference between the dry

TABLE II.
Mean number of mealybugs per tree on "moribund" and "symptom-bearing" diseased cacao.

Stage of disease	Adults			Nymphs		Total mealybugs (all locations)
	Branches	Trunk	Whole tree (including pods)	Branches	Whole tree (including pods)	
"Moribund" $\log (n + 1)$.. (n)	0.39	0.25	0.54	0.60	0.81	0.91
	1.5	0.8	2.5	3.0	5.6	7.1
"Symptom-bearing" $\log (n + 1)$.. (n)	0.82	0.80**	1.22*	1.27	1.31	1.63
	5.7	5.3***	15.6*	17.7	19.4	42.0
S.E. $\log (n + 1)$	± 0.22	± 0.09	± 0.20	± 0.28	± 0.32	± 0.30

weights of 3.62 gm. and 3.25 gm. for the healthy and infected samples respectively. A further analysis, however, showed a significant reduction ($P < 0.01$) in the percentage water content of the diseased tissue (67.9 per cent. and 66.0 per cent. for healthy and diseased tissues, respectively). In a later section of this paper it is shown that the movement of mealybugs from wilting infested cacao is related to the water content of the wood. It is probable, therefore, that many of the insects leave the infected trees when symptoms of the disease first appear.

Strickland considered that the age and consequently the size of the cacao host might affect the density of the mealybugs. From significant correlations between both girth and height of trees and the mealybug infestation, Strickland concluded that there was some evidence that the longer a cacao tree had been standing the more likely it was to be infested with mealybugs. To test this statement the present writer calculated a regression between the log girth and log ($n + 1$) mealybugs per tree on 90 trees; the transformation of the girth data was necessary to bring about a more normal distribution. From the data illustrated in fig. 1 a significant correlation coefficient ($P < 0.001$) of +0.58 was

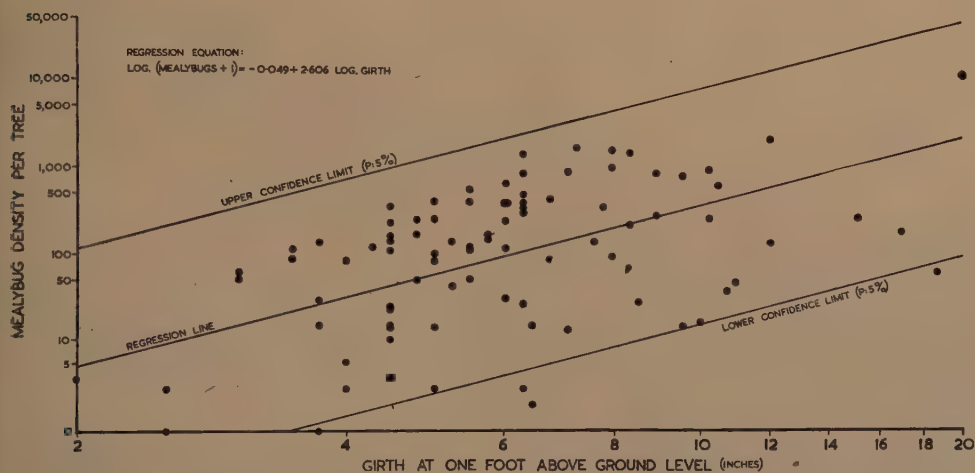


Fig. 1.—The relationship between the girth and mealybug infestation on healthy cacao. The wide confidence limits indicate the variability of the data.

obtained. The writer is in agreement with Strickland's suggestion that the higher infestation on older and larger trees would seem to make it more likely for them to become infected with the virus than younger trees with a smaller mealybug population. To investigate this suggestion a comparison was made between the distribution of girth classes of 844 infected trees and 752 healthy trees, which were randomly selected from spot plans of the same 72-acre farm (fig. 2). The statistical probability obtained in the chi-squared test of significance ($P = 0.99 - 0.98$) approximates to unity, demonstrating the very close fit of the two distributions and indicating that on this farm, where there is a close canopy, young trees of small girth and older trees with larger girth are equally susceptible to infection. There is accordingly no evidence to support the suggestion that large mature trees supporting large populations of mealybugs are more susceptible to the disease.

To summarise, there is evidence that the mealybug population on trees felled during the process of cutting out and formed into slash piles is usually low. This may be associated with a reduced water content of the host tissue resulting from infection. The mealybug population in slash piles formed during the treatment

of old outbreaks, in which the trees are in an advanced stage of swollen shoot disease and which give the visual appearance of dying from drought, may contain an even lower population than slash piles formed in areas of recent infection where the trees retain an intact canopy. Slash piles contain 98 per cent. of the mealybug population. They may be composed of diseased trees of all stages of maturity.

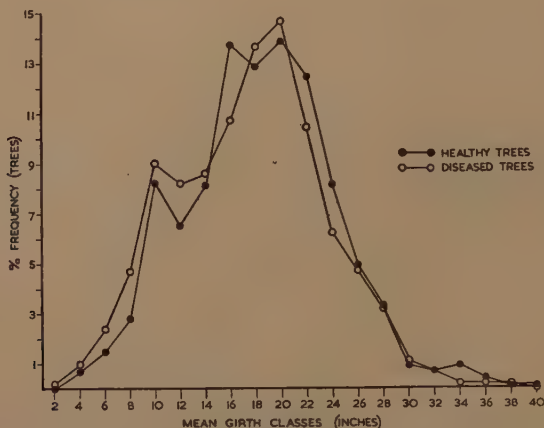


Fig. 2.—Girth distributions of healthy and recently infected cacao.

Conditions within Slash Piles.

It has been pointed out that, until 1948, diseased trees were not formed into slash piles but were left in the positions where they were felled. Strickland (1951a) recorded that mealybugs could still be found 18 days after felling on heavily infested mature trees, but that they were entirely absent by the 24th day. On smaller, less heavily infested trees all specimens had disappeared by the eleventh day after felling.

To study the environmental conditions to which mealybugs are subjected in slash piles, the shade temperature of the outside atmosphere and the temperatures at the centres of two piles were measured over a period of three weeks after pile formation. Records were also made for a period of one week in two piles three months after their formation. Rate of evaporation within piles was measured using Livingstone atmometers which were protected in wooden crates with open slatted lids to permit air movement. Three piles were constructed with base diameters of 7.6, 6.0 and 5.1 ft., each containing two atmometers at their centres, and two instruments similarly crated were placed under shade conditions outside the piles.

The results shown in fig. 3 indicate that there is no appreciable increase in temperature within the piles from the time of formation. Even after three months the mean pile temperature does not greatly exceed that of the outside atmosphere. It is apparent, however, that the cut wood produces an insulating effect, greatly influencing the magnitude and time of day/night fluctuations. This is more evident in larger piles. In piles of decreasing size, 19.9, 15.6 and 35.4 cu. cm. of water were evaporated from atmometers over a period of 28 days. The evaporation outside the piles was 43.2 cu. cm. Analysis of the results indicated that there was a significantly lower rate of evaporation ($P < 0.05$) at the centres of the two largest piles but the conditions within the smallest pile approached those of the outside atmosphere. It is possible, however, that differences in evaporation in the atmosphere are masked at the feeding sites of

the mealybugs by the presence of carton ant tents which form independent micro-climates.

These experiments showed that trees which were cut before the introduction of piling were subject to higher rates of evaporation and more extreme temperatures than exist within slash piles. This resulted in the more rapid wilting of

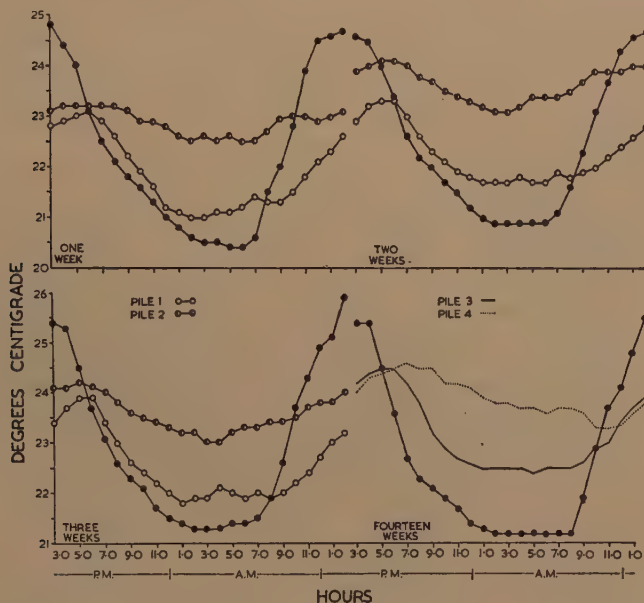


Fig. 3.—Weekly mean atmospheric and pile temperatures recorded in piles of various sizes at various periods after pile formation. Atmospheric shade temperatures are represented by blackened circles. The dimensions of the piles, in ft., are as follows;

Pile	Height	Base diameter
1	7	11
2	10	16
3	5	9
4	6	11

the cut wood and the disappearance of the mealybug population. Further experiments were carried out to investigate the effect of pile conditions on the rate of wilting of the felled trees and the behaviour of the mealybug population.

The Wilting of Cacao and its Effect on Mealybug Behaviour.

In the first experiment (1), the state of wilting of cut cacao in slash piles of various sizes was determined from samples of 32 four-in. pieces of wood taken four and eight days after felling. A representative sample was obtained by taking eight pieces of wood from each of the north, south, east and west sides of the piles at each of the three positions "outside", "middle" and "centre". Because it was known that the water content varies with the thickness of the wood it was necessary to standardise the samples. This was achieved by selecting from each sample only those pieces of wood having a dry weight within the range of 1 to 2 gm.; this is equivalent to a diameter of about one centimetre. The mean percentage water content of the sample was then calculated from these selected pieces.

The effect of wilting of infested cacao on the number of mealybugs moving away from the cut wood ("mealybug migration") was investigated by comparing

the rate of migration over paper from thin cacao shoots which wilted rapidly and from thicker, more slowly wilting shoots (2). Pieces of cut wood, with diameter ranges of 4 to 7 mm. and 8 to 20 mm., supporting large numbers of mealybugs, were placed in small separate piles at the centres of two sheets of paper. "Target twigs" of cacao †, which had been fumigated in a hydrogen cyanide chamber to free them of mealybugs, were placed at opposite ends of the sheets at a distance of 18 inches from the "migration piles". Two similar piles of non-infested shoots, the "weighing piles", were placed on a third sheet of paper. The three sheets were separated from each other by a thick smear of banding grease and this design was replicated seven times. Daily weighings were made of the "weighing piles" and mealybugs were recorded on the target twigs which were renewed by fresh pieces.

The effect of wilting on the reproduction of adult mealybugs was studied by counting the number of adults and nymphs supported by 250 six-week-old cacao seedlings (3). The nymph/adult ratio of the population supported by five "healthy" seedlings growing in nutrient culture solution was compared with the ratio obtained from five "wilting" seedlings growing in dry sand. Seedlings were examined on the 3rd, 6th, 9th, 12th and 15th days of wilting and the design was replicated five times. Each vessel was surrounded by target twigs of cacao which were examined daily and replaced by fresh twigs. The seedlings were also examined on their appropriate days and a final ratio was calculated from the combined counts. Because adults were absent in two plots, resulting in ratios of infinity, an analysis of variance was calculated on the adult/nymph ratios, which provided zero values for these plots. To obtain a more normal distribution of the data a square-root transformation was necessary.

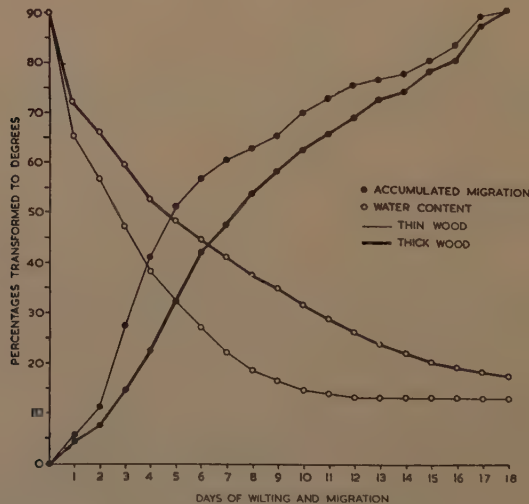


Fig. 4.—The migration of mealybugs from thick, slowly wilting cacao and from thin, rapidly wilting wood. The accumulated percentage migration and percentage water contents have been transformed to angles to assist in the clarity of the illustration.

† The use of fresh target shoots of cacao as bait for recording the numbers of migrating mealybugs was found to be very satisfactory and this technique was subsequently employed in many laboratory and field experiments. It was shown that the vast majority of mealybugs which reached these shoots settled and commenced feeding. The shoots could be easily examined under the binocular microscope and the insects removed and mounted for instar identification. This technique was found to be more satisfactory than a sticky trap.

The results of the first experiment (1) indicated that cut cacao wilts more rapidly in piles smaller than 70 cu. ft. (significant at $P < 0.05$) than in piles larger than this size. The values of 58 per cent. and 63 to 68 per cent. were obtained for the water contents of the cut wood in piles smaller and larger than 70 cu. ft. The results also showed that wilting occurs more rapidly on the outside than within the piles (significant at $P < 0.001$). The water content values of 65 to 66 per cent., 63 to 65 per cent. and 60 to 64 per cent. were obtained for the sampling positions "centre", "middle" and "outside" respectively. There was no rain-fall during the experiment and no significant decrease in water content was recorded between four and eight days.

The results of the second experiment (2) showed that for each day of wilting there was a highly significant difference ($P < 0.001$) between the water contents of the thin and thick wood (fig. 4). On the first two days of wilting, when only 2 to 4 per cent. of the mealybugs had left the cut wood, there was no significant difference between the rates of migration; from the third to ninth day there was a significantly faster rate of migration (P varying from < 0.5 to < 0.001) from the "thin" piles than from the more slowly wilting "thick" piles. From the tenth day onwards, after about 80 to 90 per cent. of the mealybugs had left the cut wood, differences in rate of wilting did not influence the rate of migration. It may be concluded that the rate of wilting of infested cacao is an important factor determining the rate of mealybug migration from the cut wood.

The results of the last experiment (3) showed that wilting seedlings support a significantly higher ratio ($P < 0.05$) of nymphs/adults than healthy seedlings (Table III). The reproduction induced by wilting ceases at about the sixth day,

TABLE III.

Mean $\frac{\text{nymph}}{\text{adult}}$ ratios of mealybug populations on fresh and wilting seedlings
(after retransformation of $\sqrt{\frac{\text{adult}}{\text{nymph}}}$ data).

Condition of seedlings	Days					Means
	3	6	9	12	15	
"Healthy" ..	1.31	2.27	4.31	5.72	1.85	2.48
"Wilting" ..	1.66	6.57	5.26	7.07	5.78	4.36*
Means ..	1.47**	3.60	4.75	6.34	3.01	

after which there is no significant increase in the ratio. The steady rise of the ratio on the healthy seedlings from the third to twelfth day indicates an increase in the nymphal population by normal reproduction; the anomalous value obtained for the ratio on the fifteenth day cannot be explained.

To summarise, the results of these experiments have shown that the movement of mealybugs from cut cacao is related to the wilting of the wood. Wilting of felled cacao is retarded by pile formation, thereby retarding the rate of mealybug migration from the felled trees. The results have also shown that reproduction of the mealybugs is stimulated as cacao starts to wilt, which may provide higher populations in piles soon after their construction than existed on the trees before felling.

The Effect of Piling on Mealybug Populations.

The majority of ant tents and mealybugs in slash piles are protected from direct sun radiation and rainfall by the leaning trunks and heavy branches. The first of a series of experiments was carried out to investigate the effect of sheltered and exposed conditions on the persistence of ant tents and mealybugs on cut cacao in the field. Further experiments were designed to study mealybug populations in piles of different ages.

In the first experiment (1), cut cacao branches were formed into eight small heaps on the ground, each containing 200 ant-tented mealybug colonies. Temporary shelters of palm and plantain were constructed over four heaps, selected at random, and the other heaps were left exposed. A sample of colonies at the time of formation of the heaps showed that 95.6 per cent. were inhabited. Counts were made of the number of ant tents and mealybug colonies persisting in one pair of heaps, "sheltered" and "exposed" at six-day intervals.

In the second experiment (2), comparisons were made between the frequency distribution of colonies containing different numbers of mealybugs sampled from cacao trees before felling and the distributions of the residual population in slash piles 10 and 20 days after formation. To determine the effect of piling on the predator population, counts were obtained of the number of colonies containing Coccinellid and Cecidomyiid larvae. The pre-piling sample consisted of 1,000 colonies taken from 216 trees. The figure for colonies with zero population was arrived at by counting the number of carton ant tents that were found on examination to contain no mealybugs. It includes any disintegrated tents recognisable as such. The trees were then cut out and formed into eight slash piles each composed of 27 trees. Counts were made of mealybugs in 877 colonies from 4 piles, selected at random, 10 days after their construction, and further counts were obtained from 730 colonies in the remaining four piles 20 days after formation. Following this, another sample of 1,000 colonies was taken from the remaining infested trees growing in the same area.

It is probable that during the construction of slash piles mealybug colonies become evenly distributed throughout the piles. In the next experiment the

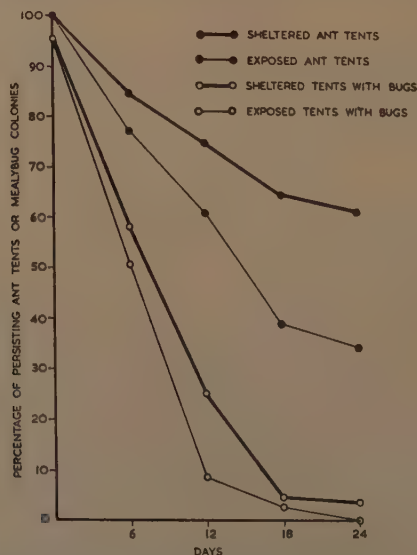


Fig. 5.—The effect of sheltered and exposed conditions on the persistence of ant tents and mealybugs on wilting, infested cacao.

relative positions of the residual population in a slash pile 8 feet high and with a base diameter of 11 feet were determined six weeks after pile formation. The pile contained an estimated original population of 18,241 mealybugs†, and the relative positions of 19 colonies containing 593 bugs, were recorded by measuring the height of each colony above the ground and its distance from a vertical pole at the centre of the pile. In a further experiment, three slash piles each five feet high with a base diameter of seven feet, containing a total estimated population of 24,593 bugs, were examined 20 days after their formation. The relative elevations of the residual population of 508 insects were recorded at 1-ft. levels above ground.

In a final experiment (3), laboratory investigations were made into the geotactic response of migrating mealybugs. Pieces of cut infested cacao were pinned to seven vertical boards (replicates) which were separated by a thick smear of banding grease. Target twigs of cacao, which were free from mealybugs, were pinned two feet above and below the central sources of bugs. Insects were recorded for a period of 15 days.

The results of the first experiment (1), shown in fig. 5, indicate that mealybugs and ant tents persist longer under sheltered conditions than when exposed to

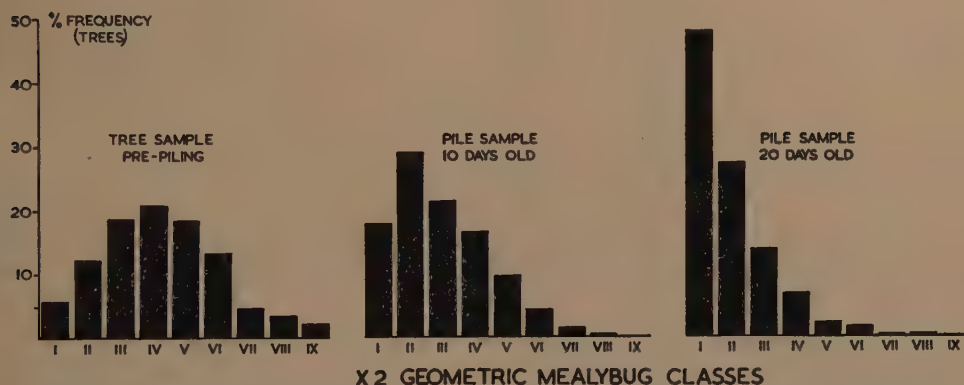


Fig. 6.—Frequency distributions of colonies containing different numbers of mealybugs sampled from trees before felling and from slash piles 10 and 20 days after construction. The mealybugs have been grouped in X 2 geometric classes as follows;

Class	No. of bugs	Class	No. of bugs
I	0	VI	31- 62
II	1- 2	VII	63-126
III	3- 6	VIII	127-254
IV	7-14	IX	255-510
V	15-30		

The numbers of colonies in these classes have been expressed as percentages to assist in comparison of the data.

the effects of direct rainfall and sun radiation. Mealybugs leave the cut wood and the empty ant tents slowly disintegrate. In a comparison (2) of the mealybug populations on trees before felling and after piling (fig. 6) chi-squared tests indicated highly significant differences ($P < 0.001$) between the colony distributions of the samples from the trees and 10-day-old piles ($\chi^2 = 70.8$), and between the samples from the 10-day and 20-day piles ($\chi^2 = 67.9$). These

† Mealybug populations in slash piles were calculated from regression equations of significant correlations between the girths measured at one foot above the ground and the mealybug populations of a sample of trees taken in the experimental area immediately before the felling of those trees required for pile construction. It must be stressed that the figures quoted are estimates and serve to indicate only the order of magnitude of the pile populations employed.

differences result from higher frequencies in the smaller mealybug classes and lower frequencies in the larger classes, indicating a decrease in population with the age of the pile. A comparison of the samples obtained from trees at the beginning and end of the experiment showed that no significant change in the population on the trees had occurred. The data obtained for the predator populations indicated that whilst piling had no effect on the 2 per cent. of colonies containing Cecidomyiid larvae, there was a decrease in the number of colonies containing larval Coccinellids from 13 per cent. of tree colonies to 5 per cent. and 1 per cent. of colonies in 10-day-old and 20-day-old piles.

The results of the first experiment to study the position of the residual mealybug population in slash piles showed that the majority of colonies were located towards the bottom of the pile. This result was confirmed by the findings of the second experiment (fig. 7) from which it may be concluded that

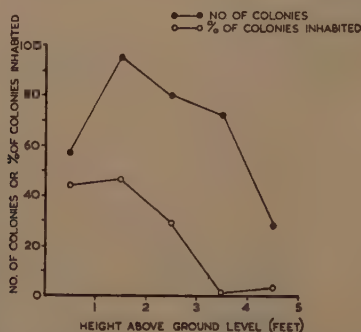


Fig. 7.—The numbers of mealybug colonies and percentage of colonies inhabited at various elevations in slash piles 20 days after construction.

on the two criteria, number of colonies and percentage of colonies inhabited, the residual population appears to be centred at the 1- to 2-ft. level above the ground. The results of the experiment to study the geotactic response of mealybugs (3) indicated that there was no significant tendency for bugs to exhibit either positive or negative geotaxis. The location of the residual population towards the bottom of piles may not therefore be attributed to a downward movement of the population. During the examination of piles, first-instar nymphs were frequently found as long as eight weeks after pile formation. The duration of the first instar varies from 4 to 13 days (Strickland, 1951a) and it is evident therefore that conditions within piles are suitable for mealybug reproduction.

To summarise, the results of these experiments have shown that the number of mealybugs in slash piles slowly decreases with the age of the piles and their persistence is aided by the slow rate of wilting of the wood and by the protection of ant tents and colonies from direct sun radiation and rainfall. Mealybugs continue to live and reproduce within heaps for many weeks and the colonies which survive longest are those in the lower parts of the heaps where desiccation of the material is most delayed. It has been shown in the previous section that reproduction of the mealybugs is stimulated as the tissues of the felled trees start to wilt and this may be responsible for the presence of nymphs in piles many weeks after their formation. The concentration of mealybugs in piles produces a decrease in the population of Coccinellid larvae which becomes more marked with the age of the pile, but it has no effect on the population of Cecidomyiid larvae.

The Mobility of Mealybugs in the Laboratory.

It had been assumed, and general field experience supported the assumption, that the vast majority of mealybugs on felled trees died without having any opportunity of re-establishing themselves on neighbouring healthy trees and of spreading infection. Further support to this belief was given as a result of Strickland's work (1951a), from which he drew the conclusion: "It is thus clear that ant-assisted migration and successful establishment does take place from felled mealybug infested trees, but that such establishment is on a small scale, and mostly does not take place until any virus in the felled tree has died."

There are three limiting factors associated with the spread of the disease from slash piles, the persistence of the virus in an active form in the cut wood, the persistence of the virus in an active form in the mealybug, and the unassisted and ant-assisted movement of mealybugs across the ground to healthy trees.

Strickland (1951a) showed that the virus remains active in the cut wood for a maximum of 14 days after felling, but detailed information on the state of wilting of such wood is not available. Posnette & Robertson (1950) showed that infective adult mealybugs which were starved for a maximum period of 36 hours were capable of transmitting the virus. Lister (1953) has more recently shown that this period may be extended to 49 hours. For first-instar nymphs this period is about 24 hours. Strickland (1951a) showed that young adult *P. njalensis*, when disturbed, walk quite long distances, at a maximum speed of about 5 ft. in 20 minutes, in search of new feeding sites. More normally such migration is taken in stages, punctuated by resting periods.

The most important factor, therefore, concerning the infection of healthy trees by mealybugs moving away from slash piles, is the speed with which they can reach the surrounding trees. A series of laboratory experiments was therefore conducted to investigate the form of the migrating mealybug population; the mobility of mealybugs over various migration surfaces and the effect of starvation on their movement and length of life. These were followed by field experiments to study the distance to which mealybugs migrate from slash piles.

In the first experiment (1), to study the form of the migrating population, a total of 8,941 mealybugs migrating over paper from wilting infested cacao were recorded on target cacao twigs and were examined for instar identification.† In the second experiment (2) the speed at which ten first-instar nymphs and 24 adults walked over paper was recorded by tracing their paths for periods of 15 minutes. A further 16 adults, which had been starved for 24 to 48 hours, were similarly tested. To investigate further the effect of starvation on the mobility and length of life of *P. njalensis*, insects were contained in muslin-stoppered tubes without food. To determine whether or not the starved insects were capable of walking, they were placed on smooth paper and observed for a period of five minutes.

The last experiment (3) of this series was carried out to compare the effect of three migration surfaces, smooth paper, sand and soil with cacao litter, on the mobility of *P. njalensis*. The three migration surfaces were replicated four times and an estimated number of 280 insects was placed in a compact group at one end of each of the 12 plots. The number of insects which migrated to target cacao twigs over a distance of 12 to 30 inches during 48 hours was recorded and the mean nymph/adult ratio of the migrating population was calculated.

† For the accurate identification of instars, all the specimens were mounted for microscopical examination. The instars of *P. njalensis* may be distinguished by the number of antennal joints and the length of the hind tibiotarsus. It is not possible to distinguish between mealybug species in their nymphal stages. However, as *P. njalensis* occurs at a density of 100 times that of *P. citri* (Risso), the next most common mealybug (Strickland, 1951b), it was assumed that all specimens were of the former species. The error in instar identification may therefore be of the order of about 1 per cent.

The results of the first experiment (1) showed that 77.7 per cent. of the total of 8,941 migrating mealybugs were first-instar nymphs; 12.5 per cent. were second-instar nymphs, 3.7 per cent. were third-instar nymphs and 6.1 per cent. were adults. Examination of the cut wood in an advanced state of wilting showed that adults tend to remain at their feeding sites and frequently die there. It has been shown that mealybug reproduction may be induced by wilting of the infested cacao, and therefore the high percentage of first-instar nymphs recorded may be attributed to the sum of the existing population plus the progeny. That the migrating first-instar nymphs do not form a homogeneous population is shown by the series of histograms in fig. 8. The prominence of the two peaks in the daily

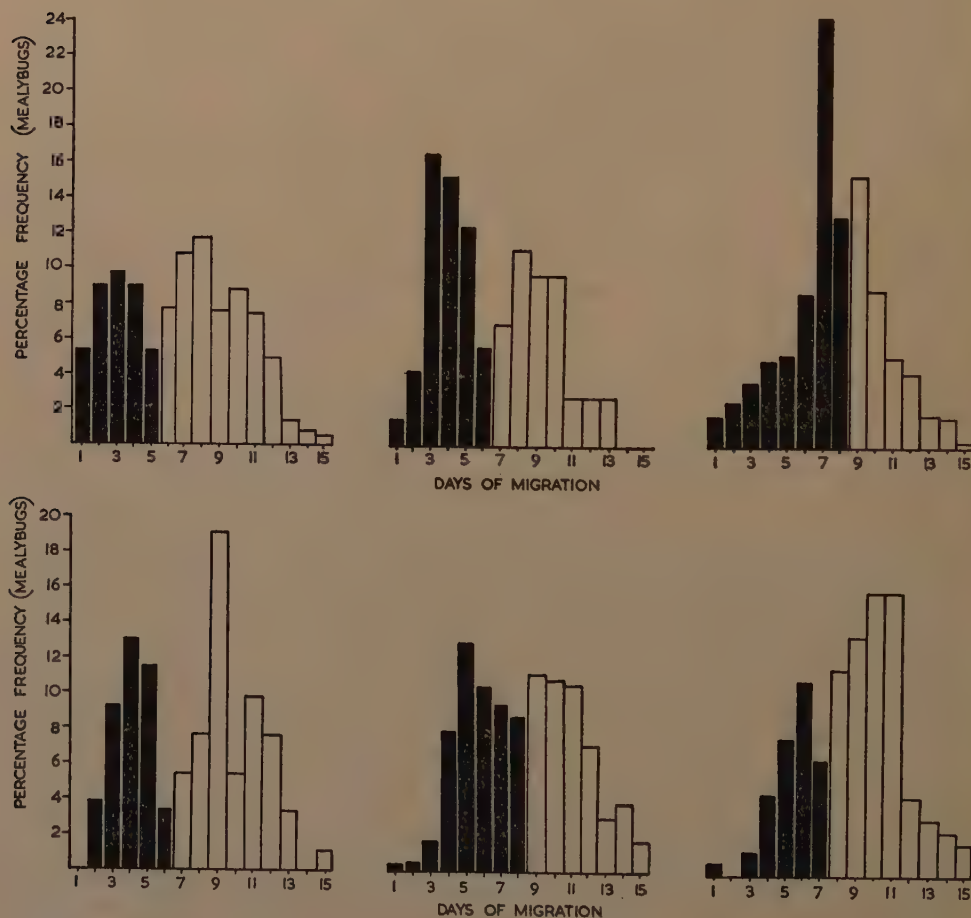


Fig. 8.—Histograms demonstrating the heterogeneity of first-instar nymph populations migrating from wilting, infested cacao in six laboratory experiments. The illustration emphasises the presence of two peaks in each distribution.

captures may be associated with the proportion of first-instar nymphs to adults on the infested cacao, the rate of wilting of the cut wood influencing the rate of reproduction and the rate of migration of the existing nymphal population. In the second experiment (2) the recorded mean speeds of 2.24 and 2.04 in. per minute for the movement of first-instar nymphs and adults, respectively, were

not significantly different. These rates were calculated only from the periods which the insects spent in motion. A preliminary starvation period significantly reduced the speed of movement of adults ($P < 0.001$) to 1.32 in. per minute. Preliminary starvation did not significantly affect the value of 5 per cent. of the

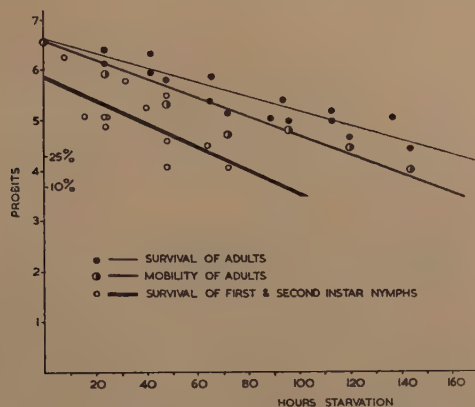


Fig. 9.—The effect of starvation on the length of life of first- and second-instar and adult mealybugs. Also the effect of starvation on the capacity for movement of adults.

test period spent in resting. From the results of the experiments to investigate the effect of starvation on the length of life and mobility of mealybugs (fig. 9) it may be concluded that if first- and second-instar nymphs are subject to complete starvation, 90 per cent. die within 4 days; 90 per cent. of completely starved adults are incapable of movement within $6\frac{1}{2}$ days and die within $8\frac{1}{2}$ days. The results of the last experiment (3) indicate (Table IV) that the coarse migration

TABLE IV.

The effect of migration surface on the mobility of *P. njalensis*.
Mean number of mealybugs per plot.

Migration surface	Paper	Sand	Soil and cacao litter
Log n	1.57*	1.33	0.83
	S.E. = ± 0.16	S.D. = ± 0.55 at $P = 0.05$	
n	37*	21	7
Mean $\frac{\text{nymph}}{\text{adult}}$ ratio per plot	3.51*	0.87	0.45
	S.E. = ± 0.65	S.D. = ± 2.26 at $P = 0.05$	

surface exerts a significant retarding effect on the number of migrating mealybugs. Also, the retarding effect of soil and cacao litter is greater for the nymphs than the adults as shown by the significant change in the nymph/adult ratio.

Mealybug Migration in the Field.

In the first three experiments (1), comparisons were made between the numbers of mealybugs which migrated over cacao litter to target cacao twigs from small heaps of infested cacao and the numbers which migrated under the same conditions over a smooth plywood surface. These experiments were also designed to investigate the effect of associating the mealybugs with *Crematogaster* ants. This was achieved by placing nests of *Crematogaster striatula* Emery, contained in pieces of dead wood, with either the target twigs or the source colonies. The migration surface was eight feet long and the treatments, replicated six times, were randomised in position in the field. Mealybugs were recorded on the target twigs over a period of 14 days.

A further series of experiments (2) was carried out to study the distance to which mealybugs migrate from slash piles. In the first experiment, six slash piles were formed from healthy cacao, each composed of 50 to 100 trees and containing estimated populations varying from 10 to 20 thousand mealybugs. The soil around the piles was cleared of all vegetation within the limits of the experiment and three piles were each surrounded by rings of target cacao twigs at 3, 6 and 9 ft. and the other three piles surrounded by twigs at 5, 10 and 15 ft. Each ring contained eight pieces of target wood, each ten inches long, which were staggered in position so that direct migration paths from the pile to the outer rings were not obstructed by target twigs of the inner rings. Mealybugs were recorded for three weeks after pile formation.

In a repetition of this experiment (3), target material was placed at distances of 3, 5, 7, 9, 11 and 13 ft. from six slash piles each containing an estimated population of from four to five thousand mealybugs. The experiment was designed to study the distance of migration and to investigate whether or not migrating insects exhibit any directional orientation. The soil around each pile was clean-weeded and divided into six equal sectors. Distances of target material were randomly assigned to sectors such that treatments were laid down on the design of a "latin square". Complete rings of target material were employed and the improved design of this experiment prevented the outer rings from being shielded by the target wood of inner rings.

In the next experiment (4), six slash piles each containing an estimated population of about five thousand mealybugs were used to investigate the effect of migration surface, the distance of migration, the effect of rainfall and the possible existence of a directional orientation of the migrating population. Target twigs, staggered in position, were placed at 2½, 5 and 7½ ft. from the piles on the three migration surfaces, smooth plywood (Pl. IV, fig. 2), smooth soil (Pl. IV, fig. 3) and rough soil (Pl. IV, fig. 4). The effect of rainfall was studied by constructing temporary shelters of palm and plantain leaves six feet above the plots (Pl. IV, fig. 4). The randomisation of treatments around the piles on the design of a "latin square" permitted the study of an orientation effect as investigated in the previous experiment. The entry of insects into the plots from sources other than the piles was prevented by smearing the edges of the plywood boards with grease and by surrounding the soil plots with greased lengths of palm midrib. Mealybugs were recorded for 18 days after pile formation.

In the last experiment (5), a study was made of those mealybugs which migrate from piles, those which become dislodged from the trees at the time of cutting out, and those which are airborne. Four slash piles containing estimated populations of some two thousand insects were each surrounded by six 2-ft. square quadrats of palm midrib. The quadrats were pressed firmly into the soil and the exposed upper surfaces of the wood were thickly smeared with banding grease. From two quadrats at each pile, the side adjacent to the pile was removed, leaving the outer three edges in position; into these plots it was possible for mealybugs to migrate from the piles, to be shaken to the ground at

the time of felling and to be carried by wind. In two other quadrats, a 1-in. layer of soil was compacted on to the existing soil surface killing any mealybugs present; mealybugs recorded in these plots must have been airborne from outside sources. The remaining pair of quadrats were not modified in any way; mealybugs recorded in these plots may have been present on the soil or may have entered by aerial migration. Five pieces of target material were randomly placed in each quadrat and mealybugs were recorded over a period of four weeks.

The results of the first three experiments (1), shown in Table V, confirmed the observations made in the laboratory, that soil with cacao litter exerts a marked retarding effect on the mobility of mealybugs. The total of 71 mealybugs which migrated over litter was less than 6 per cent. of the 1,235 insects which migrated over the smooth artificial surface. About 95 per cent. of the insects recorded on plywood and 80 per cent. of those recorded on litter were first-instar nymphs which may be compared with 78 per cent. obtained in the laboratory. Except in the first experiment, the presence of *Crematogaster* ants appeared to have no significant effect on migration. In this one instance, significantly fewer mealybugs ($P < 0.05$) were recorded on the plywood plots in the presence of nests than in their absence.

In the first experiment with slash piles (2), a total of 132 mealybugs was recorded, representing 0.13 per cent. of the estimated pile populations. An

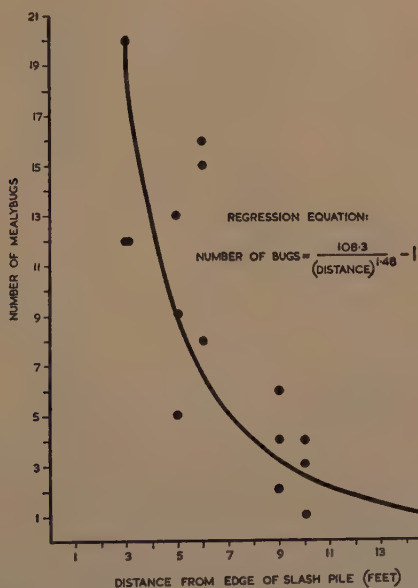


Fig. 10.—Numbers of mealybugs recorded on target cacao twigs at various distances from slash piles containing estimated populations of 10 to 20 thousand mealybugs. The captures represent the total numbers of insects recorded during the first three weeks after pile construction.

analysis between the numbers of insects and their distance of migration provided the significant correlation coefficient ($P < 0.001$) of -0.85 , indicating that migration from the piles had occurred. The results shown in fig. 10 indicate a rapid decrease in captures at greater distances from the piles; when the distance is doubled the number of mealybugs is reduced to about one third. Extrapolating from the curve, no captures are expected at distances further than 24 feet from the piles.

TABLE V.
The effect of migration surface and presence or absence of nests of *Crematogaster striatula*
on the migration of *P. rufidensis*. Mean number of mealybugs per plot.

Experiment	1			2			3		
Position of ant nests	With source colonies			With source colonies			With target cacao twigs		
Number of mealybugs per plot	1,800			1,500			2,000		
Treatment	No ants	Ants	Mean	No ants	Ants	Mean	No ants	Ants	Mean
Plywood $\log(n+1)$	1.41*	0.95	1.18***	1.03	1.29	1.14***	1.44	1.17	1.31
n	25.0*	.78	14.1***	9.7	18.5	12.9***	26.8	13.9	19.4***
Soil with litter $\log(n+1)$	0.38	0.56	0.47	0.36	0.32	0.34	0.46	0.33	0.40
n	1.4	2.6	1.9	1.3	1.1	1.2	1.9	1.1	1.5
S.E. $\log(n+1)$	± 0.13		± 0.09	± 0.10		± 0.07	± 0.19		± 0.14
Mean $\log(n+1)$	0.90	0.75		0.70	0.80		0.95	0.75	
n	6.9	4.6		4.0	5.4		8.0	4.7	
S.E. $\log(n+1)$	± 0.09			± 0.07			± 0.14		

In the second experiment with slash piles (3), only 59 insects, which represented 0.22 per cent. of the estimated pile populations, were recorded in a period of 14 days. Although the number of insects recorded was small, an analysis of the data was attempted. More mealybugs were recorded in the south and south-west sectors, and fewer insects were taken at 11 and 13 ft. from the piles, but these differences did not approach statistical significance.

In the third experiment (4), only 36 mealybugs, which represented 0.12 per cent. of the estimated pile populations, were recorded over a period of 18 days. A total of 1.54 in. of rain fell during the experiment but there was no significant difference in the number of mealybugs recorded under exposed and sheltered conditions. More mealybugs were recorded from the plywood plots than from the soil plots ($P < 0.001$) and although migration was more marked in the smooth soil than in the rough soil, this difference did not reach statistical significance. Fewer mealybugs were recorded at greater distances from the piles and more insects were taken from the south and south-east sectors, but these differences were not significant.

In these three experiments it was shown that the numbers of mealybugs migrating from slash piles and recorded on target twigs was only a very small percentage of the estimated pile populations. It was shown with some certainty that soil seriously impedes migration, but only in the first of these experiments employing piles with extremely high populations was it possible to show a decrease in captures at greater distances from the piles. These results indicate, therefore, that some mealybugs captured on target twigs may have entered the experiments from sources other than the piles.

In the last experiment described (5), only 28 mealybugs were recorded during a period of four weeks. Five of these insects were recorded in plots completely surrounded by banding grease into which it was impossible for them to migrate from the piles. Three of these insects were recorded in plots into which they must have been airborne from outside sources. A significantly higher number of insects ($P < 0.05$) was recorded in those quadrats into which it was possible for insects to migrate from the piles. These results confirmed previous conclusions that mealybugs migrate from slash piles and confirmed the suggestion that airborne insects may be recorded on target twigs placed around slash piles in the manner employed in previous experiments.

To summarise, it has been shown that the vast majority of migrating mealybugs are first-instar nymphs. The nymphal population is augmented by progeny which are produced on the cut wood after felling. Mealybugs are capable of walking quite rapidly for long distances over smooth surfaces, but their speed is significantly reduced by short periods of starvation. Mealybugs soon become incapable of movement when starved for a few days and the majority die within a week. Soil exerts a marked retarding effect on their movement and this is more evident with nymphs than with adults. It has been shown with certainty that mealybugs migrate from slash piles but their distance of movement is limited to a few feet. The number of insects recorded at short distances from the piles constitutes an extremely small percentage of the estimated pile populations. Migrating mealybugs exhibit no marked directional orientation and it was shown that some mealybugs present on the soil around piles enter these areas from sources other than the piles.

Ant-assisted Migration.

Laboratory investigations into the rôle played by ants in mealybug movement provided inconclusive results. These experiments consisted of associating infested cacao or target cacao twigs with nests of *Crematogaster striatula*, and recording the numbers of migrating mealybugs on the target twigs. Field

experiments previously described, indicated (with one exception) that the presence of such nests produced no significant effect on the numbers of insects migrating from cut infested cacao to target twigs over a distance of eight ft.

A few days after the construction of slash piles, ant trails, mainly of *Crematogaster* and *Oecophylla*, are established between the piles and surrounding trees. These trails are maintained for many months after pile formation and they are usually established between the piles and surrounding forest trees and rarely with standing cacao trees. Such trails have never been observed associated with cacao trees at a distance of more than 30 ft. from slash piles. Ants leaving the piles were frequently observed carrying pieces of nest material and the following experiments were carried out to study the frequency with which they carry mealybugs.

In the first experiment, over 43,000 ants walking out of two slash piles, with a combined estimated population of almost 10,000 mealybugs, were collected during the first two weeks after pile construction. The ants, which were collected irrespective of size and species, and whether or not they were seen carrying anything, were immediately killed in spirit; ants walking into the piles were not disturbed. In a repetition of this experiment, over 37,000 ants were collected moving out of three slash piles with a combined estimated population of about 25,000 insects. The ants were collected over a period of two weeks in the same manner as described above.

In these experiments, 18 genera of ants were represented but over 90 per cent. of the insects were species of *Crematogaster*. In the first experiment, 120 mealybugs and 13 other Coccids were found in the collections. These results showed that less than 0.3 per cent. of the ants carried mealybugs, almost 80 per cent. of which were adults, and the number recorded constituted 1.2 per cent. of the estimated mealybug population of the piles. In the second experiment, 26 mealybugs and 6 other Coccids were recorded; only 0.07 per cent. of the ants carried mealybugs, 23 per cent. of which were adults, and the number constituted 0.1 per cent. of the estimated population of the piles. The difference in the percentage of adult bugs carried in the two experiments may be attributed to the dominance of *C. striatula* in the collection of the first experiment and to that of *C. africana* Mayr. in the second experiment. Many of the ants retained mealybugs in their mandibles after having been killed in spirit; bugs were found in the mandibles of only the *Crematogasterine* species, but these and *Oecophylla longinoda* (Latr.) were found carrying *Stictococcus sjöstedti* Ckll. In both experiments, the numbers of mealybugs carried by ants constitute an extremely small percentage of the pile populations.

Establishment of migrating Mealybugs on seedling and mature Cacao.

In experiments previously described, migrating mealybugs were recorded on pieces of fresh cacao wood placed on the ground and used as bait at various distances from slash piles. In the following experiments the cacao wood was replaced by seedling cacao and mature trees. It is considered that mealybugs establish themselves on cacao because the host-plant provides suitable feeding sites, and that the number of established insects found provides a relative, but not absolute measure of the numbers of insects which have fed.

In the first experiment (1), 432 two-month-old cacao seedlings were placed round three slash piles each composed of about 20 infected trees. The trees were known to be infested with mealybugs but an accurate estimation of the pile populations cannot be given. The tins containing the seedlings were sunk into the ground in three circles round each pile at distances of 3, 6 and 9 ft. Each circle contained six groups, each of five seedlings, and the groups were staggered in position without obstructing direct migration paths from the piles. One

selected seedling in each group was removed and replaced every three days by a fresh seedling. One of the four remaining seedlings, chosen at random, was removed every three days and was not replaced. Some seedlings were therefore under continuous exposure to migration for 3, 6, 9 and 12 days, whilst others were exposed only for various 3-day periods during the 12-day period of the experiment.

In further experiments (2), mealybug establishment was studied on cacao trees on which all mealybugs were previously killed by spraying with nicotine-sulphate solution or fumigating with hydrogen cyanide. The trees were enclosed in nine-ft. square plots surrounded by boards which were sunk into the ground. The upper exposed surfaces of the boards were regularly smeared with banding grease to prevent the entry of insects from outside the plots. All canopy bridges with neighbouring trees were removed. Both the experimental and control trees were treated in this way. The experimental trees were further surrounded, within the wooden barrier, by heavily infested slash on which the mealybug population was estimated from counts made from a 10 per cent. sample of colonies. After various time intervals the numbers of bugs which had established themselves on these trees were compared with populations on the adjacent control trees.

In the first of these experiments, 12 trees were sprayed on two occasions with 0.1 per cent. nicotine-sulphate solution after all the mealybugs which could be found had been removed by hand. Two weeks after spraying, nests of *Crematogaster striatula* were attached to each tree. The trees were grouped in pairs and one tree, selected at random from each pair, was surrounded by cut cacao branches supporting an estimated population of 7,000 mealybugs. The other tree was used as a control. The slash was placed at three feet from the base of the trees and after a period of three weeks the trees were felled and the mealybug population recorded.

In another experiment, 12 trees were pre-sprayed on two occasions with 0.5 per cent. and on a third occasion with 0.1 per cent. nicotine-sulphate solution. The trees were selected in four groups (replicates) each of three trees. To one of these trees was attached a nest of *C. striatula* (control), a nest was similarly attached to a second tree which was surrounded by slash supporting an estimated population of 7,500 bugs, and the third tree was surrounded by slash but was not inoculated with ants. The slash was placed immediately at the base of the trees which were examined 20 days later.

In a final experiment, 18 trees were fumigated with hydrogen cyanide. A canvas tent was constructed over each tree which was fumigated for half an hour with a mixture of 10 gm. KCN, 10 cc. H_2SO_4 (S. G. 1.84) and 20 cc. water. All the mealybugs on cacao seedlings placed in the canopies of the trees to test the efficiency of the fumigant were killed. Ant nests of *C. striatula* were attached to all trees which were grouped in pairs (replicates), and one tree selected at random from each pair was surrounded at its base by slash supporting an estimated population of 15,000 mealybugs. Mealybug populations on the trees were ascertained 8 weeks later.

In the first experiment (1), only seven seedlings supported mealybugs; five insects were recorded three feet from the piles and two insects six feet away. The captures were too few to establish the time of migration. All the seedlings were retained in the insectary for six months after the experiment and during this time none developed virus symptoms. In the experiments (2) using trees as bait, there was no significant difference between populations supported by trees surrounded by slash and the controls. Mean populations per tree were about 10 to 30 insects.

From these experiments it may be concluded that after vigorous spraying with nicotine-sulphate solution or fumigation with hydrogen cyanide, the trees so treated are soon reinfested by airborne insects. It may also be concluded that

when mealybugs are given the optimum conditions of migrating from wilting slash and of establishing themselves on new hosts, such insects placed at the base of the trees in the presence of their attendant ants fail to increase the mealybug populations.

Confirmatory Experiments using radioactive Insects.

The results of some of the field experiments previously described were difficult to interpret because of the entry of insects into the experiments from unknown sources. A laboratory technique was therefore elaborated for "labelling" mealybugs with radioactive phosphorus which enabled insects from a given experimental source to be identified with certainty and to be distinguished from all others in the field.

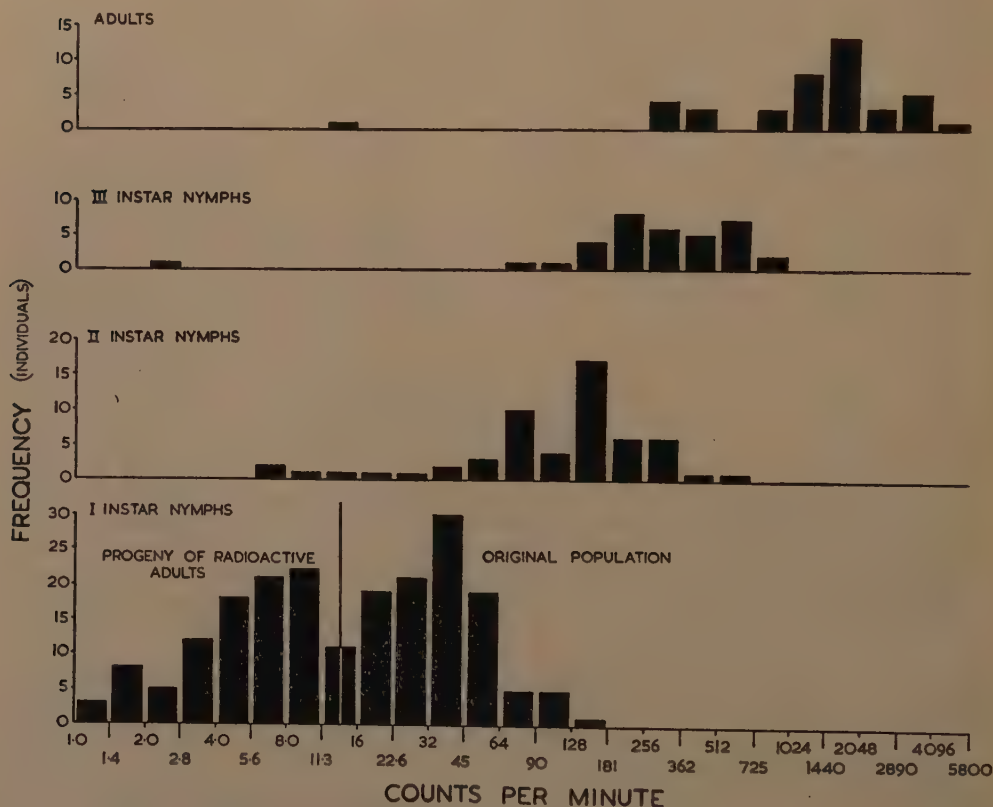


Fig. 11.—Frequency distributions of counts obtained from individual radioactive mealybugs. The data indicates the degree of radioactivation of the four instars of *P. njalensis* fed on seedlings in radioactive culture solution.

Young cacao seedlings supporting colonies of established mealybugs were grown in sand and then transferred to nutrient culture solution containing radioactive phosphorus in the chemical form of orthophosphoric acid. Such seedlings developed extensive root systems and optimum uptake of phosphorus was obtained in strong sunlight. The levels of activity used varied from 43 to 15 millicuries/litre. It has been shown (Russell & Martin 1949) that low activities of the order of 10 microcuries/litre of ^{32}P in culture solutions cause a significant

reduction in root growth. There is little doubt that the high levels of activity employed in the culture solutions of the present work produced some biological damage to the plants. They were maintained in culture for periods of from 4 to 7 days during which time, however, no macroscopic damage was apparent. Counts obtained from a sample of insects used in the following experiments are shown in fig. 11. Although the activity of adult mealybugs providing about

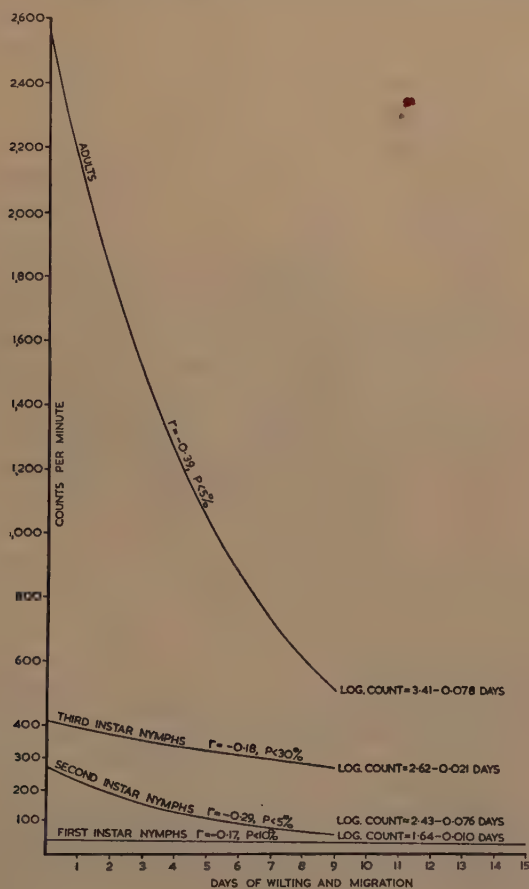


Fig. 12.—The decrease in radioactivity of the four instars of *P. njalensis* migrating from radioactive, wilting seedlings in the laboratory. The data has been corrected for physical decay.

2,000 counts/min. was considerably reduced by the excretion of radioactive phosphorus in their honeydew and by the production of progeny giving some 10 counts/min., such insects retained easily detectable levels of activity after feeding for three or four weeks on non-radioactive host-plants. The decrease in activity with time of insects migrating from wilting radioactive seedlings in the laboratory is shown in fig. 12. The negative correlations obtained for all instars indicate that the feeding activity of such insects is reduced. Higher levels of activity are excreted in the honeydew than are taken up during feeding on the wilting tissues. This result suggests that the wilting wood soon becomes unpalatable and it is therefore probable that offspring produced by adults on the wilting wood migrate without feeding on the host tissues. By means of the frequency

histogram of the activities of first-instar nymphs shown in fig. 11 it was possible to differentiate between the first-instar nymphs of the original population (above 14 c.p.m.) and those produced by adults on the wilting tissues (below 14 c.p.m.). Such differentiation showed that about 60 per cent. of the migrating first-instar nymphs were progeny resulting from "wilting-induced reproduction". If the assumption made above is correct, that these insects migrate without feeding, as seems very probable since offspring of radioactive adults cultured on non-radioactive plain agar provide comparable activities, then only about 53 per cent. of the total population of insects migrating in laboratory experiments are potential vectors.

It has been stated previously that the most important limiting factor concerning the infection of healthy trees by mealybugs moving away from slash piles is the speed with which they can reach the surrounding trees after leaving the piles. In this connection, experiments with radioactive mealybugs were carried out to determine the speed with which they migrate across soil. Firstly it was demonstrated, however, that the speed of movement of mealybugs providing counts of the order indicated was not significantly different from that shown by non-radioactive insects cultured on seedlings under the same conditions.

In the first of this series of experiments (1), 100 radioactive seedlings supporting an estimated population of 10,000 mealybugs were evenly distributed throughout a slash pile $4\frac{1}{2}$ ft. high and with a base diameter of three ft. Counts obtained from a sample of 50 first- and second-instar nymphs which had fed on these seedlings showed that all the insects were radioactive, providing counts varying from 67 to 713/min. The slash pile was formed at the centre of a block of 26 cacao trees which were sprayed two weeks previously with 0.2 per cent. nicotine-sulphate solution. The distance of the trees from the pile varied from $1\frac{1}{2}$ to 18 ft. and two weeks after pile formation the trees were carefully examined for mealybugs.

In a second experiment (2), 27 radioactive cacao seedlings supporting an estimated population of over 5,000 radioactive mealybugs were cut into small pieces and placed on a glass plate in the centre of an area of clean-weeded soil. The soil was made level with the edges of the glass plate which was surrounded by a complete ring of 144 pieces of mealybug-free cacao wood at a distance of 20 ft. After 24 hours the glass plate was removed, the cut seedlings were examined and no mealybugs were found. The target cacao twigs were examined and replaced by fresh pieces at intervals of 24, 48 and 72 hours after the mealybugs were put down.

In a repetition of this experiment (3), 38 seedlings supporting a population of 2,000 radioactive mealybugs were cut into small pieces and placed on a glass plate at the centre of a rectangle of clean-weeded soil 12 ft. long by 2 ft. wide. The edges of the rectangle were lined by a complete ring of mealybug-free cut cacao wood which was placed on the soil. Outside this ring, lengths of palm midrib were sunk into the ground and the upper exposed edges were smeared with banding grease. The target cacao wood was examined and replaced by fresh pieces at intervals of 24, 48 and 72 hours after the mealybugs were put down and the greased palm midrib was examined at the completion of the experiment. The whole area was sheltered from rain and direct insolation by a suspended tarpaulin cover. At the same time a further experiment was conducted of exactly the same design as described above except that an area of naturally deposited cacao litter was selected for the migration surface.

In the last experiment of this series (4), 40 seedlings supporting a population of 2,000 radioactive mealybugs were cut into small pieces and placed in a compact heap on a glass plate at the centre of an area of clean-weeded soil. One half of this area was covered with cacao litter to simulate the conditions found under standing cacao and the glass plate was placed on the boundary line

between the two migration surfaces. At 24 hours after the bugs were put down, radiations were measured at 20 equidistant points on a circle of 4-ft. radius around the central source. Counts were also made at these points on circles of 2-, 3- and 4-ft. radius 48 and 72 hours after the commencement of the experiment. Radiations were measured with a vertically mounted, one-in. diameter

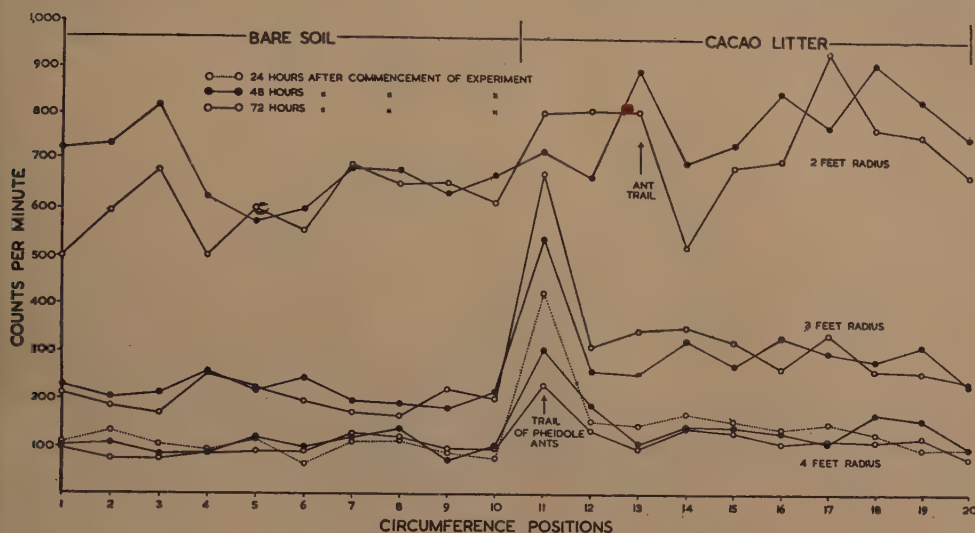


Fig. 13.—Radiation contours recorded at 2, 3 and 4 ft. from a central source of radioactive mealybugs on radioactive, wilting seedlings. The position of a trail of radioactive ants is indicated. The data has been corrected for physical decay.

end-window Geiger Müller counter at a distance of 5 in. above the ground and the counts obtained and corrected for physical decay are shown in figs. 13 and 14. Soon after the bugs were put down they were attended by numerous ants of the genus *Pheidole* which established a trail between the source and their nest at some distance outside the experimental area. This trail crossed the area on the cacao litter near position 13 at 2 ft. from the source and position 11 at 3 and 4 ft. radius. These ants became radioactive by the imbibition of radioactive honeydew, and a sample of ants taken three days after the commencement of the experiment gave counts varying from 88 to 709/min. The position of the ant trail is clearly indicated by the higher counts recorded at the positions stated above.

In the first experiment (1), a total of 209 mealybugs were located on the 26 trees surrounding the pile containing radioactive insects. These mealybugs were tested in the laboratory and not one provided a count significantly greater than the background count. Insects removed from the pile gave counts varying from 48 to 715/min. These results showed that there was no evidence of migration from the pile to the surrounding trees and that those insects recorded on the trees had come from sources other than the pile. In the second experiment (2), to investigate migration over a distance of 20 ft. of clean-weeded soil, a total of eight first-instar nymphs was recorded on the target wood and was tested in the laboratory. Not one of these insects was radioactive, indicating that they had entered from outside the experimental area. It must be noted that there was 1.7 in. of rain during the experiment which may have contributed to the retarding effect of soil surface on migration. In the experiments protected from rain by a tarpaulin cover (3), no mealybugs were found on the target wood or the greased

palm midrib surrounding the area of clean-weeded soil. Seven mealybugs were found on the target wood surrounding the area of cacao litter but only two of these insects were radioactive; one third-instar nymph migrated 18 in. within 48 hours and gave a count of 439/min. and one adult migrated 30 in. within 72 hours and gave a count of 657/min. No mealybugs were recorded on the greased palm midrib. At the end of the experiment, 72 adults and 61 nymphs had not moved further than the edges of the glass plate on the clean-weeded soil and 111 adults and 189 nymphs remained at the source in the area of cacao litter; the majority of these nymphs were offspring of radioactive adults.

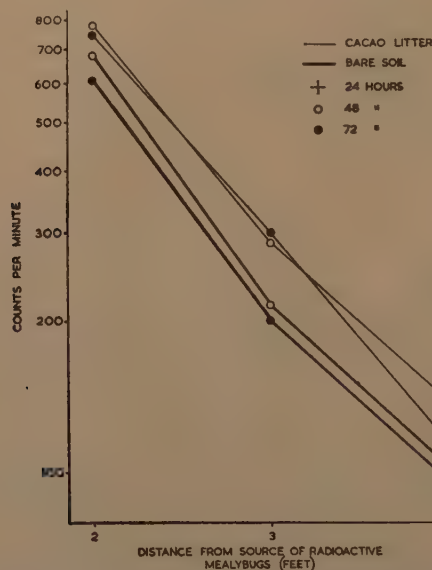


Fig. 14.—Mean radiation counts recorded at 24-hourly intervals at 2, 3 and 4 ft. from a central source of radioactive mealybugs. The data has been corrected for physical decay.

The results of the final experiment (4) shown in fig. 13 indicate that counts obtained at 2 ft. from the source are clearly more variable than those recorded at distances of 3 and 4 ft. This result suggests that intrusions of migrating insects reached a distance of 2 ft. within 48 hours of the commencement of the experiment. It may be noted that radiations from migrating mealybugs at greater distances from the source would be more marked against the lower background radiation provided by the central wilting seedlings. Counts recorded at 4 ft. from the source form a smooth contour suggesting that migration to this distance did not occur. These observations are illustrated in fig. 15, in which the standard errors of the mean counts have been plotted against the latter, calculated for the three distances, two migration surfaces and for the daily observations. (These means and standard errors were calculated with the omission of the very high counts recorded at the positions where the ant trail crossed the experimental area.) The larger standard errors nearer the central source are indicative of a greater variation of the counts. The incidence of migration beyond the 2-ft. radius would be demonstrated by an increase in radiation with time at greater distances from the central source. The results shown in fig. 14 indicate that the radiations recorded at 24, 48 and 72 hours approximate very closely to each other. Analysis of the results indicated that

there was no significant increase in the counts recorded at successive time intervals. Counts obtained on litter, however, were significantly higher than those recorded over soil, except at the 4-ft. ring at 72 hours. From the results of this experiment it may be concluded that there is no evidence of migration over soil further than a distance of about 2 ft. from the source. Migration occurred over cacao litter but not to distances exceeding 4 ft. within 72 hours.

The results of experiments using radioactive mealybugs confirmed the conclusion that a soil surface seriously impedes their movement. Not one insect of

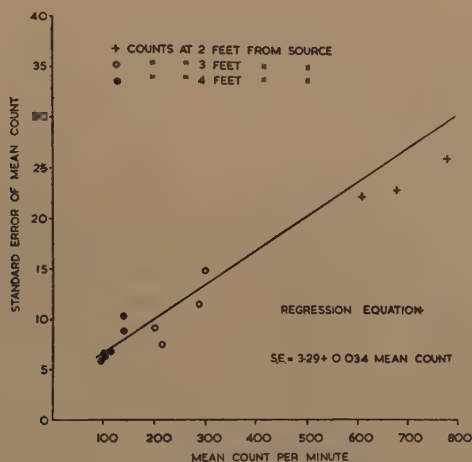


Fig. 15.—Increase in standard error with the mean count of radiations recorded at 2, 3 and 4 ft. from a central source of radioactive mealybugs. The data illustrates a greater variability of the counts obtained at positions nearer the source.

a population of 10,000 mealybugs in a slash pile established itself on healthy trees within 14 days; not one of over 5,000 mealybugs migrated a distance of 20 ft., and not one of a population of 2,000 insects migrated a distance of 2 ft. over soil during the period in which the virus may remain active within them. Only two out of a population of 2,000 mealybugs migrated to a distance not exceeding 30 inches over cacao litter within 72 hours, and in a further experiment there was no evidence of migration to a distance of 4 ft. over litter within the same period.

Discussion.

Strickland (1951a) showed that, in the Gold Coast, there is a considerable amount of migration from established mealybug colonies by freshly moulted nymphs and that young adults are easily disturbed by external stimuli. Kirkpatrick (1950) states that, in Trinidad, actively moving individuals of *P. citri*, especially full-sized adults, can nearly always be seen on any moderately infested cacao tree. He also states (*l. c.*) that only the crawler stages of *P. brevipes* Ckll., which is usually covered by ant tents, have been seen to move of their own volition. Strickland (1951a) points out that there is little doubt that the interlocking canopy of West African cacao is ideal for the dispersal of *P. njalensis* from tree to tree. The circumstances commented upon by Kirkpatrick (1950), that "cacao trees in contact with an already infected tree are more likely to become infected than those not in contact, although isolated infections are by no means unknown", apply equally to West Africa. In Trinidad, Kirkpatrick believes that this may be accounted for by the natural movements of *P. citri*.

Pseudococcid crawlers are carried by air currents in the Gold Coast, more particularly in the dry season (Strickland, 1950), but except in the case of *P. bukobensis* Laing (Strickland, 1947) there is little direct migration and successful establishment of mealybugs over the litter and on to fresh hosts (Strickland, 1951a). Kirkpatrick (l. c.) suggests that virus-spread may partly be attributed to the practice, during harvesting, of making dumps of ripe pods before splitting them to remove the beans and in this way mealybug colonies on pods are moved about within a plantation. Strickland (1951a) states that ant-assisted migration occurs in the Gold Coast but Kirkpatrick (1954) notes that none of the ants found attending mealybugs on cacao in Trinidad have ever been observed transporting their hosts.

The investigations of the present work have shown that mealybug populations in piles of infected slash, particularly those made from trees in an advanced state of disease, are usually low. The surfaces of clean-weeded soil and cacao litter seriously impede the terrestrial movement of mealybugs, and insects which leave slash piles are not capable of migrating to healthy trees at distances greater than 4 ft. from the piles in the period during which the virus may persist within them. Mealybugs may be carried to greater distances by ants but the number of insects transported in this manner constitutes a very low percentage of the populations on the felled trees. Even in the presence of their attendant ants the establishment of mealybugs on their new hosts is very poor. The process of "cutting out" is therefore an efficient method of controlling the spread of the virus from diseased to healthy trees.

The piling of infected slash is undoubtedly an improvement upon the practice of leaving the diseased trees where they were felled. By the construction of piles the vector populations may be concentrated at sites at greater distances from healthy trees, where the insects persist for longer periods than on felled trees subject to rapid desiccation. Suggestions have been made for burning the piles to eliminate the vector populations. This practice is difficult to effect with cacao in the fresh state, particularly in the wet season. Burning after pile construction would destroy the valuable source of fuel of which the cultivators take advantage when the felled trees have dried out, about three or four months after piling, and in the light of the present results such burning is unnecessary.

Cutting out and construction of slash piles inactivate the virus in the diseased trees after about 14 days and provide conditions which inhibit the spread of potential vectors. Increased efficiency of the control method could be obtained by speeding up the cutting-out programme with the removal of diseased trees as soon as possible after infection. This would eliminate vectors when their numbers on the diseased hosts are at a maximum. The control method becomes inefficient when diseased trees are left in the field until they have reached an advanced stage of infection. Under these circumstances the vector populations have left their hosts before cutting out, the existing populations on the diseased trees are very low and frequently non-existent and the trees no longer provide favourable hosts for the infection of newly establishing insects. It is the practice in Nigeria to cut out at initial treatment both the diseased and apparently healthy contact trees. In the Gold Coast this has not been possible, and in consequence it is necessary to make frequent re-inspection of treated areas and to remove the trees which have subsequently developed symptoms. It has been shown that about one-third of the contact trees surrounding disease outbreaks are latently infected (Posnette, 1952). Whilst these trees remain standing, sources of vectors exist to infect further contact trees and possibly other healthy trees at greater distances by wind-borne vectors. Without the co-operation of farmers in supporting the removal of contact trees in the Gold Coast, no further recommendation can be advanced to improve the present method of control of swollen shoot.

Summary.

Mealybug populations (*Pseudococcus njalensis* Laing) originally present in piles of slash infected with the virus of swollen shoot of cacao are usually small. It is suggested that many of the insects leave the trees at an early stage in the development of infection.

Slash piles offer conditions which induce mealybugs to remain within them. The piling of infected slash retards the rate of wilting of the cut wood and consequently retards the rate of migration of the mealybug population. The construction of piles protects the mealybugs from direct insolation and rainfall and leads to the persistence of the population on the cut wood. The colonies which survive the longest are those in the lower part of the heaps where death and desiccation of the material is most delayed.

Mealybugs continue to live and to reproduce within heaps of slash for as long as nine weeks or more. Reproduction of the mealybugs is stimulated as the tissues of the felled trees become wilted and the resulting first-instar nymphs contribute numerous participants to such migration as does occur. There is evidence from laboratory experiments that these insects are not potential vectors.

The concentrating of mealybugs in slash piles produces no increase in the population of Coccinellid or Cecidomyiid larvae within the piles.

Mealybugs are capable of walking quite rapidly for long distances over smooth surfaces. They become incapable of movement when starved for a few days and the majority die within a week. A soil surface seriously impedes the progress of mealybugs which leave the slash heaps and this effect is more marked with the nymphal stages. Even on clean-weeded soil the rate of travel is slow and few, if any, insects can travel over appreciable distances in the period during which the virus may persist within them. Results of preliminary experiments were confirmed by the use of insects labelled with radioactive phosphorus.

Some of the ants, which become associated with slash piles and which remain in attendance of the residual mealybug population, carry mealybugs, but the number of insects transported in this way is of little practical significance.

The establishment of migrating mealybugs on seedlings and mature cacao is poor even in the presence of their attendant ants.

All these factors make the possibility of infecting healthy trees from infected slash extremely remote. There is accordingly no reason to believe that the efficiency of "cutting out" is seriously reduced by the movement of vectors from the infected trees which are cut out.

Without the co-operation of farmers in supporting the removal of contact trees no further recommendations can be advanced to improve the present method of control of swollen shoot.

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References.

- BAWDEN, F. C. (1955). The spread and control of plant virus diseases.—Ann. appl. Biol., **42**, pp. 140–147.
- CORNWELL, P. B. [1955]. Mealybug population, distribution and migration.—Proc. W. Afr. int. Cacao Res. Conf. 1953, pp. 8–17.
- GOODALL, D. W. (1949). Virus diseases of cacao in West Africa. IV. Effect of virus infection on growth and water content of cacao seedlings.—Ann. appl. Biol., **36**, pp. 440–447.
- KIRKPATRICK, T. W. (1950). Insect transmission of cacao virus disease in Trinidad.—Bull. ent. Res., **41**, pp. 99–117.
- KIRKPATRICK, T. W. [1954]. Notes on minor insect pests of cacao in Trinidad.—Rep. Cacao Res. 1952, pp. 62–71. Trinidad, Imp. Coll. trop. Agric.
- LISTER, R. M. (1953). West African Cacao Research Institute. Annual Report, April, 1952 to March, 1953, pp. 9–10.
- POSNETTE, A. F. (1952). Virus research at the West African Cacao Research Institute, Tafo, Gold Coast.—Trop. Agriculture, **28**, pp. 133–142.
- POSNETTE, A. F. & ROBERTSON, N. F. (1950). Virus diseases of cacao in West Africa. VI. Vector investigations.—Ann. appl. Biol., **37**, pp. 363–377.
- RUSSELL, R. S. & MARTIN, R. P. (1949). Use of radioactive phosphorus in plant nutritional studies.—Nature, Lond., **163**, pp. 71–72.
- STRICKLAND, A. H. (1947). Coccids attacking cacao (*Theobroma cacao*, L.), in West Africa, with descriptions of five new species.—Bull. ent. Res., **38**, pp. 497–523.
- STRICKLAND, A. H. (1950). The dispersal of Pseudococcidae (Hemiptera—Homoptera) by air currents in the Gold Coast.—Proc. R. ent. Soc. Lond., (A) **25**, pp. 1–9.
- STRICKLAND, A. H. (1951a). The entomology of swollen shoot of cacao. I. The insect species involved, with notes on their biology.—Bull. ent. Res., **41**, pp. 725–748.
- STRICKLAND, A. H. (1951b). The entomology of swollen shoot of cacao. II. The bionomics and ecology of the species involved.—Bull. ent. Res., **42**, pp. 65–103.
- WILLIAMS, C. B. (1937). The use of logarithms in the interpretation of certain entomological problems.—Ann. appl. Biol., **24**, pp. 404–414.
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FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.

A slash pile constructed during an experiment to determine the effect of soil surface and rainfall on the distance of mealybug migration. FIG. 1. General view of pile; FIG. 2. Plywood surface (4A); FIG. 3. Plywood surface (4A); FIG. 4. Rough soil (4C) and plywood surface sheltered from rainfall (4D). Mealybugs were captured on target cacao twigs at $2\frac{1}{2}$, 5 and $7\frac{1}{2}$ feet from the edges of the pile.

STUDIES ON THE BIONOMICS OF THE CASE-BEARING CLOTHES MOTH, *TINEA PELLIONELLA* (L.).

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(PLATE V.)

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Tinea pellionella (L.) (Fam. TINEIDAE), commonly known as the Case-bearing Clothes Moth or Fur Moth, is a cosmopolitan household pest of woollen materials. It has been reported as occurring in west and central Asia, India, Ceylon, Japan, Australia and New Zealand, North America, North and South Africa and Europe (Fletcher, 1920). The literature available on this species is limited to its taxonomy, popular accounts of the life-history and records of damage to various materials. The taxonomy of the adult *T. pellionella* has been studied by Fletcher (1920) and Hayhurst (1942), of the egg by Pappenheim (1938) and of the larva by Fletcher (1920). General accounts of its life-history have been given by Herrick (1914), Marlatt (1915), Bruneteau (1930), Back & Cotton (1931), Kemper (1934, 1935), Yamada (1940) and Jenkins (1944). Damage by this pest has been recorded on a wide range of materials which include woollen fabrics, furs and feathers (Marlatt, 1915), nests of birds, stuffed birds, upholstered furniture, brushes, pith-helmet, balaclava cap and deer skin (Fletcher, 1920), alpaca, camel hair, cashmere, goat hair and sheep fleece (Burgess & Poole, 1931), stored tobacco, piano keys, aconite roots, cayenne pepper, horse-radish, cherry, laurel leaf, black mustard seed, ginger, orris root, linseed, almonds and saffron (Hayhurst, 1942).

No investigations on the life-history, general biology and behaviour of this species under controlled conditions have been reported. In view of the great economic importance of this insect, it was considered important to study these aspects in a systematic and comprehensive manner. Such a study, apart from its fundamental importance, was expected to aid in rearing standard cultures of the insect under laboratory conditions and in establishing a standard procedure for the assessment of treatments of woollen fabrics.

The insects used in the investigations were drawn from cultures maintained in the laboratory. These cultures were derived from infested woollen materials from a local storehouse. Temperature was controlled in incubators, while different relative humidity levels were obtained by the use of aqueous potassium hydroxide solutions of varying strengths (Buxton & Mellanby, 1934).

The Egg.

The egg (Pl. V, fig. 1) is creamy white when freshly laid but gradually turns pale red. It is oval in outline, slightly broader at one end than at the other. When examined under a binocular microscope, the surface shows longitudinal furrows which become more distinct as development progresses. The dimensions of 27 eggs were as follows:—

	Length (mm.)	Width (mm.)
Maximum	0.615	0.338
Minimum	0.477	0.292
Mean \pm S.E.	0.523 \pm 0.0065	0.313 \pm 0.003

The incubation period and viability of eggs.

The incubation period and percentage viability of eggs were investigated at various levels of temperatures and humidity. The results are summarised in Table I.

TABLE I.

Incubation period and percentage viability of eggs.

Temp. (°C.)	R.H. (%)	No. of eggs	Percent. viability of eggs	Period of incubation (days)
14 \pm 0.5 ..	90	50	0	—
21.5 \pm 0.5 ..	30	„	80	4 - 5
„ ..	90	„	86	4 - 5
25 \pm 0.5 ..	30	„	86	5
„ ..	90	„	90	5
30 \pm 0.5 ..	30	„	80	7
„ ..	90	„	72	6 - 7
32.5 \pm 0.5 ..	30	„	46	6 - 7
„ ..	90	„	56	6 - 7
34.5 \pm 0.5 ..	30	„	0	—
„ ..	90	„	0	—

It will be observed that at lower temperatures the incubation period is shorter and the percentage viability greater than at higher temperatures. Eggs fail to hatch at 34.5 \pm 0.5°C. Humidity has no influence on the incubation period or viability of eggs.

The Larva.

Before hatching, the larva gradually cuts the chorion with its mandibles from the broader end of the egg. As soon as the opening is of the size of its head, it emerges with the help of its thoracic legs and ultimately wriggles out of the egg

shell. A freshly hatched larva is pale yellow in colour. The dimensions of 20 freshly hatched larvae are given below:—

	Length (mm.)	Width (mm.)
Maximum	1.0	0.215
Minimum	0.892	0.169
Mean \pm S.E.	0.99 \pm 0.001	0.202 \pm 0.0025

When the larva is 2 or 3 days old the dorsum of the first thoracic segment turns brown. Later, with the growth of the larva, it becomes dark and conspicuous. The dorsum is divided into two plates by a longitudinal band (Pl. V, fig. 2).

The freshly hatched larva crawls about on the food material for about 24 hours, at the end of which it settles down. The construction of the case which also commences at this stage is brought about by binding small bits of fibres (cut from the feeding material) with silken threads spun by the larva. From the outside, the case appears rough but the inside is smooth and lined with silk. The larva takes about 24 hours to build the case (Pl. V, fig. 2) and once it is built it starts wandering again.

As the larva grows it enlarges the case and, at each moult but the last, it throws the head capsule out of the case. A larva is capable of making a complete turn within the case and this enables it to feed on the food material at either end of the case without altering the position of the case (Pl. V, fig. 3).

While crawling, the larva protrudes outside the case to about half its length and holds on to the surface of the feeding material by means of hooks present at the tips of the thoracic legs. It then pulls forward the posterior half of the body along with the case by wriggling movements, helped by the crochets borne on the planta of the prolegs of the third, fourth, fifth, sixth and ninth abdominal segments. The larva is thus enabled to carry the case along with it while crawling.

The number of hooks on the prolegs varies from 16–17 and these are in uniordinal series arranged in a penellipse, except on the ninth segment where they are arranged in a semicircle.

TABLE II.

Duration of larval period under various physical conditions.

Serial no.	Temp. (°C.)	R.H. (%)	No. of larvae	Duration of larval period (days) (Mean \pm S.E.)
1	13.5 \pm 0.5	95 \pm 5	10	No development
2	21.5 \pm 0.5	30	10	68 \pm 1.2
3	"	90	10	46 \pm 1.9
4	25 \pm 0.5	55 \pm 5	7	41 \pm 0.96
5	"	90	11	33 \pm 0.42
6	30 \pm 0.5	30	7	86 \pm 5.29
7	"	90	9	73 \pm 2.16
8	30 \pm 1.5	72.5 \pm 2.5	6	48 \pm 2.5
9	32 \pm 1.5	70 \pm 10	9	87 \pm 2.8
10	32 \pm 0.5	30	10	Larvae died within 7 days
11	"	90	10	83 \pm 2.4
12	34.5 \pm 0.5	30	10	Larvae died within 2 days
13	"	90	10	Larvae died within 7 days

A larva removed from its case is capable of building a fresh one, except when it is very near pupation, when, not being able to build a new case, it dies. The dimensions of 20 full-grown larvae are given below:—

	Length (mm.)	Width (mm.)
Maximum	7.5	1.35
Minimum	4.0	1.11
Mean \pm S.E.	5.99 \pm 0.19	1.21 \pm 0.032

Larval period.

The larval period was studied at different temperatures and humidity levels by liberating, separately, freshly hatched larvae in specimen tubes containing "standard" * woollen fabric impregnated with 10 per cent. yeast **. The results are shown in Table II.

The results show that at the same temperature, higher humidity favours shorter larval period. The shortest larval period is at 25°C. and 90 per cent. R.H.

Number of larval instars and their duration.

In order to study the number of instars and their duration at different levels of temperature and humidity, a number of freshly hatched larvae was liberated separately in specimen tubes containing woollen fabric treated with 10 per cent. yeast. Results are shown in Table III.

It will be observed that the number of larval instars at 21–25°C. is smaller than at 28.5–31.5°C. There is some indication that higher humidity favours a lesser number of larval instars. Frequently, at the same temperature and humidity, different larvae in the same batch behave differently in respect of the larval instars they pass through prior to pupation.

Measurements of head capsules.

In order to ascertain whether Dyar's law (Dyar, 1890) holds good in the case of the present insect, three larvae were kept separately at 25°C. and 90 per cent. R.H. and the measurements of head capsules at each moult were recorded. The results shown in fig. 1, in which the logarithm of the (average) head-capsule

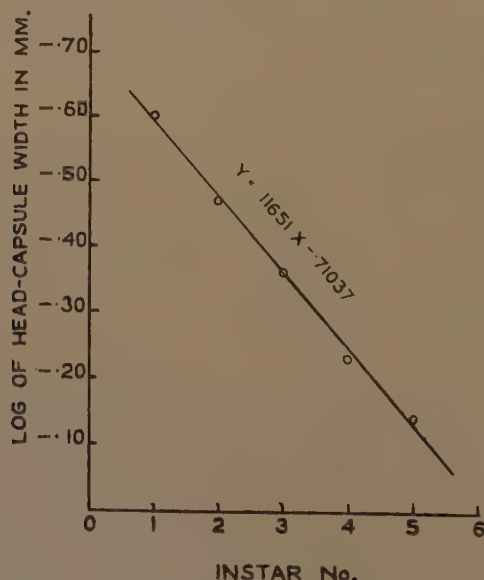


Fig. 1.—Diagram illustrating application of Dyar's law.

* Standard woollen fabric used in these investigations was all wool white worsted serge, 54 inches wide, weighing 12½ oz. per linear yard.

** As dispersion in water.

TABLE III.

Number of instars and duration of each instar.

Temp. (°C.)	R.H. (%)	No. of larvae	Total no. of instars	Duration (in days) of each instar (Mean \pm S.E.)											
				I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
21.5, \pm 0.5	30	10	6	12 \pm 0.0	10.2 \pm 0.13	10.4 \pm 0.27	11.2 \pm 0.5	11.3 \pm 0.4	12.8 \pm 1.4						
	90	10	5	9 \pm 0.0	6.4 \pm 0.3	6.8 \pm 0.3	8.9 \pm 0.7	11.8 \pm 1.8							
25 \pm 0.5	55 \pm 5	7 { 2 5	5	9 9.2 \pm 0.2	7.5 6.2 \pm 0.2	8.5 7.6 \pm 0.9	7 6.2 \pm 0.6	7.5 5.4 \pm 0.7	6 \pm 1.05						
	90	11	5	9 \pm 0.0	4 \pm 0.0	4 \pm 0.0	7.5 \pm 0.28	8.7 \pm 0.36							
30 \pm 0.5	30	1	8	8	6	7	8	9	5	7	6	10	12		
	"	1	9	10	9	8	5	10	8	11	10	8.5	11	8.5	
	"	2	10	10	7.5	8	6.5	9.5	7.5	9	11	8.5	7		
	"	2	11	8.5	8.5	7.5	6.5	9	8	8.5	10.5	8.5			
	"	1	12	8	7	9	5	3	9	8	8	9			
	90	2	8	10.5	6.5	7	8	10.5	6.5	9	10.5	7.8 \pm			8
	"	5	9	9.8 \pm	6.8 \pm	6.8 \pm	6.2 \pm	9.2 \pm	7.6 \pm	8.8 \pm	8.2 \pm	0.12			
	"	1	10	0.5	0.2	0.8	0.6	1.5	0.4	0.9	1.2	9	8		
30 \pm 1.5	"	1	10	10	11	9	6	9	7	15	8				
	72.5 \pm 2.5	6	7	7 \pm 0.0	6 \pm 0.6	6.5 \pm 0.3	6.5 \pm 0.6	6 \pm 0.4	10 \pm 1.8	5.5 \pm 0.5					

width has been plotted against the instar number, are in conformity with Dyar's law.

Growth.

Freshly hatched larvae were measured for length and thickness and also weighed. They were then released on standard woollen fabric treated with 10 per cent. brewers' yeast and kept at 25°C. and 90 per cent. R.H. Further

TABLE IV.

Growth measurements of freshly hatched and fully grown larvae.

Serial no.	Stage of larva	Length (mm.)		Width (mm.)		Weight (gm.)	
		Num-ber	Mean \pm S.E.	Num-ber	Mean \pm S.E.	Num-ber	Mean \pm S.E.
1	Freshly hatched	20	0.997 \pm 0.001	20	0.203 \pm 0.0025	100	0.0031
2	Fully grown	20	5.99 \pm 0.19	20	1.21 \pm 0.032	100	0.4154
	Ratio between 1 and 2	1 : 6		1 : 6		1 : 134	

measurements of length, thickness and weight were made when they stopped feeding before pupation. The results are summarised in Table IV.

It will be observed that while a larva only increases its length and width by 6 times during its development, it puts on 134 times its initial weight.

TABLE V.

Developmental period (hatching of egg to emergence of adult) at $30 \pm 1.5^\circ\text{C}$. and 70 to 75 per cent. R.H. on different food materials.

Food material	No. of larvae	Percent. larval development	Developmental period (in days) Mean (range)
All-wool fabric, type I, impregnated with 10% yeast	10	100	42 (35-50)
All-wool fabric, type II, impregnated with 10% yeast	10	100	43 (38-49)
Cotton/wool fabric (50 : 50) impregnated with 10% yeast	20	85	74 (60-80)
Hog bristles	10	80	121 (100-137)
Barrack blanket	10	60	131 (124-139)
Woollen felt	10	50	128 (124-133)
All-wool fabric, type I, impregnated with 5% malt extract	10	30	131 (124-137)
All-wool fabric, type I	10	20	111 (100-123)
All-wool fabric, type II	10	10	130
Cotton/wool fabric (50 : 50)	10	} No development	
Cotton fabric with yeast	10		
Cotton fabric without yeast	10		
Horn	10		
Jute fabric	10		
Jute fabric impregnated with 10% yeast	10		
Wheat flour and yeast (90 : 10)	10		
Silk	10		

TABLE VI.

Development of larvae on coloured fabrics at $25 \pm 0.5^\circ\text{C}$. and $55 \pm 5\%$ R.H.

Nature of dye on woollen fabric	Shade	No. of larvae	With no nutrient		With 10% yeast on the fabric	
			Percentage larval development	Average developmental period (days)	Percentage larval development	Average developmental period (days)
Acid black H.A. 10% (Ciba) ..	Black	10	10	121	100	47
Acid blue RBF 4% (Ciba) ..	Blue	10	20	124	100	49
Lissamine green V.S. 2.5% (I.C.I.)	Green	10	0	0	100	44
Kiton red G 4% (Ciba) ..	Red	10	10	127	80	49
Crocein scarlet 3 B.S. 1.5% (I.C.I.)	Red	10	10	142	100	56
Coomassie red R 150 3% (I.C.I.)	Red	10	20	129	100	50
Cloth fast red GRG 4% (Ciba) ..	Red	10	30	137	100	50
Cloth fast orange G 4% (Ciba) ..	Orange	10	0	0	0	0
Cloth fast orange G 4% (Ciba) ..	Orange	30	0	0	0	0
Nil	White	10	10	130	100	41

Development on various foods under controlled conditions.

Experiments were carried out to study the development of larvae on different food materials at $30 \pm 1.5^\circ\text{C}$. and 70 to 75 per cent. R.H. by liberating a known number of freshly hatched larvae on them. The results are shown in Table V.

The impregnation of woollen fabrics with yeast (10%) not only enables all the larvae to develop but reduces the period of development to a minimum. Hog bristles, even without being impregnated with yeast, serve as a good food material. A fabric containing a mixture of cotton and wool (50:50) is not satisfactory but the impregnation of such a fabric with yeast renders it acceptable to the insect. Cotton, silk, horn, jute fabric and wheat flour mixed with yeast do not support development of the insect.

Larval development in relation to the colour of the dyed woollen fabric.

Experiments were conducted to study the larval development on variously coloured fabrics. Two sets of pieces ($2'' \times 1''$) of the standard woollen fabric (see p. 170) were dyed to different colours, and one of each of these two sets was subsequently impregnated with 10 per cent. yeast. Both the sets were then exposed to freshly hatched larvae and the period of development up to the emergence of adults was recorded. The results are shown in Table VI.

It will be observed that the larvae fail to develop on the woollen fabric dyed with *Lissamine green* and *Cloth fast orange* but this by itself does not appear striking since the survival rate of larvae on other fabrics is only of the order of 10 to 30 per cent. When, however, impregnated with yeast, all the dyed fabrics except the one dyed with *Cloth fast orange G 4 per cent.* favour development.

In a separate experiment, larvae 15 to 20 days old were released on fabric treated with *Cloth fast orange G 4 per cent.* and impregnated with yeast. Their fate was investigated, and it was found that all the larvae completed their

TABLE VII.

Effect of direct sunlight on the larvae.

Temp. (°C.)	R.H. (%)	Age of larvae (days)	No. of larvae exposed	Behaviour of larvae towards sunlight
32	55	2-3	30	All larvae came out of their cases within 30 minutes and died.
"	"	22-23	50	Larvae came out of their cases within 20 minutes but did not die. They were then removed and brought indoors. They were found to rebuild their cases.
39.4	50	2-3	50	Larvae came out of their cases and all died within 5 minutes.
"	"	20	50	Larvae came out of their cases, became restless within 4 minutes and all died within 15 minutes.
45	60	7	50	Larvae came out of their cases and died within 4 minutes.
"	"	15-20	50	Larvae came out of their cases within 2 minutes. All died during a period of 10 minutes.
"	"	30-35	50	Larvae came out of their cases within 4 minutes and died within 10 minutes.

development. It is obvious that this particular dyestuff inhibits the growth of freshly hatched larvae only.

Behaviour of the larvae towards bright sunlight.

Larvae of different age groups were exposed to direct sunlight at Kanpur in the month of May 1952. Temperature and relative humidity of the site at the time of exposure were recorded. Observations on the reactions of the larvae were made in the hope that the results might indicate that the infestation could be exterminated by exposure of the infested material to sunlight. The results are summarised in Table VII.

It will be observed that the larvae of all age groups are sensitive to direct sunlight and, under the conditions of the experiment, emerge from their cases on exposure to sun, irrespective of temperature and humidity. At higher temperatures (39–45°C.) they all die very soon (5–10 minutes) after emergence. It was shown in Table II (p. 169) that survival is possible at 32°C. at high humidity. This seems to show that temperature alone may not be the factor driving the larvae out of their cases when exposed at 32°C. (Table VII); sunlight also appears to be a contributory factor.

Effect of light and darkness on the extent of damage caused by the larvae.

In order to ascertain the effect of, firstly, light alternated with darkness and, secondly, complete darkness on the extent of damage caused by this insect, larvae of known age were liberated in specimen tubes (4" × 1½") each containing a piece (2" × 1") of the standard woollen fabric (see p. 170) impregnated with 10 per cent. yeast. One such set of six tubes was kept continuously in darkness while another set of six was left on the laboratory bench, thereby exposing them alternately to light and darkness. At the end of the exposure period (10–15 days) the percentage loss in the weight of the fabric was recorded. The results are summarised in Table VIII.

TABLE VIII.

Effect of light and darkness on the damage caused by the larvae.

Temp. (°C.)	R.H. (%)	Conditions under which the experiment was carried out	Period of exposure (days)	Percent. loss in weight (Mean ± S.E.)	Value of 't'
26.5 ± 0.5	61 ± 6	In darkness ..	15	19.2 ± 1.6	2.8*
"	"	Alternately in light and darkness ..	15	14.03 ± 1.02	
28.4 ± 0.6	62 ± 7	In darkness ..	10	12.8 ± 0.77	3.7**
"	"	Alternately in light and darkness ..	10	9.3 ± 0.4	

The number of larvae used in each experiment was 10, and their age was 15 days.

There were six replicates of each experiment.

* Significant at 5% level. ** Significant at 1% level.

Under the conditions of the experiment, the damage to the fabric maintained in darkness was significantly greater than the damage to that maintained alternately in light and darkness.

Effect of temperature and humidity on the extent of damage caused by the larvae.

The effect of temperature and humidity on the extent of damage caused by the larvae was also investigated. Larvae, 20 days old, were used in this experiment. The results are shown in Table IX.

TABLE IX.

Effect of temperature and humidity on the extent of damage caused by the larvae.

Temp. (°C.)	R.H. (%)	No. of replicates	Percent. loss (Mean \pm S.E.)	Value of 't'
27.5 \pm 0.5	90	6	21.1 \pm 1.46	4.03*
27.5 \pm 0.5	30	5	12.9 \pm 1.13	
32.5 \pm 0.5	90	6	18.14 \pm 0.94	1.5**
27.5 \pm 0.5	90	6	21.1 \pm 1.46	

The number of larvae used in each experiment was 10, their age was 20 days, and the period of exposure 10 days.

* Significant at 1% level. ** Not significant.

It will be observed that at 27.5°C. the percentage loss is significantly higher at 90 per cent. R.H. than at 30 per cent., showing that humidity influences the extent of the damage caused by the larvae. The difference in loss at temperatures of 27.5°C. and 32.5°C. at 90 per cent. R.H. is not significant.

Prepupal period.

Fully grown larvae generally leave the food material and crawl along the walls of the container. During the prepupal period, after fixing their cases (Pl. V, fig. 4), they close one end with fine silken threads and remain inactive within. Observations on 14 larvae have shown that the prepupal period is 4.4 \pm 0.4 days at 26.5 \pm 0.5°C. and 70 \pm 5 per cent. R.H.

TABLE X.

Duration of the pupal period.

Temp. (°C.)	R.H. (%)	No. of pupae investigated	Pupal period in days (Mean \pm S.E.)
21.5 \pm 0.5 ..	30	10	19 \pm 0.45
	90	10	18 \pm 0.4
25 \pm 0.5 ..	55 \pm 5	10	9.3 \pm 0.3
	90	9	10.3 \pm 0.16
30 \pm 0.5 ..	30	11	9.7 \pm 0.27
	90	10	10.3 \pm 0.33

The Pupa.

Pupation and the pupal period.

With the end of the prepupal period the larva casts its last larval skin within the case and pupates. Outwardly, there are no indications of the larva having pupated. To ascertain the exact time of pupation, fully grown larvae were liberated separately in glass dishes. After they had attached their cases to the glass surface a few cases were carefully examined daily from the open end without disturbing the larvae within to see whether pupation had taken place. Results are shown in Table X.

Humidity has no influence on the pupal period but at higher temperatures (25 to 30°C.) the period is shorter.

The freshly formed pupa is pale yellow in colour and turns dark brown before emergence of the adult. The dimensions of female and male pupae, 20 of each, are as follows:—

	Female		Male	
	Length (mm.)	Width (mm.)	Length (mm.)	Width (mm.)
Maximum	5.5	1.20	5.0	1.0
Minimum	4.0	1.0	3.5	0.8
Mean	4.97 \pm 0.12	1.1 \pm 0.15	3.9 \pm 0.4	0.94 \pm 0.09

The Adult.

Emergence.

There are no external symptoms to suggest the imminence of emergence. At the time of emergence, the anterior half of the pupa protrudes from the case and the adult emerges leaving the pupal shell protruding from the case (Pl. V, fig. 5).

The adult is light brown in colour with three dark spots forming the apices of a triangle on each forewing. The hind wings are yellowish brown in colour, shiny and fringed with long slender scales along the posterior margin (Herrick, 1914). In superficial appearance a particularly dark moth may be mistaken for *Tinea columbariella* Wocke but the latter differs in having slightly broader and more unicolorous forewings with apex more rounded and less produced and by the absence of first discal and plical spots (Bradley, 1950).

The males, being smaller and lighter than the females, are active fliers, while the females are sluggish and fly only for short distances. Copulation (Pl. V, fig. 6) takes place within 12 hours of emergence and lasts on an average for 34 minutes at 26.5 \pm 0.5°C. and 70 \pm 1 per cent. R.H.

Oviposition.

A female starts laying eggs 1 to 6 days after emergence. The eggs are laid singly on, or inside the folds of, woollen fabrics. The preoviposition, oviposition and postoviposition periods and the number of eggs laid have been studied and the results are shown in Table XI. Eggs are also laid by unmated females but such eggs do not hatch.

Relationship between weight of the female at emergence and the number of eggs laid.

Normal females drawn from a culture maintained at 28.5 \pm 0.5°C. and 85 \pm 5 per cent. R.H. were weighed individually on emergence and then liberated

separately in specimen tubes (4" x 1½"). In each tube a freshly emerged normal male was also introduced. If the male died earlier than the female, it was replaced by another normal male. The number of eggs laid by the female was recorded. The results are shown in Table XII.

TABLE XI.

Preoviposition, oviposition, postoviposition periods and number of eggs laid by a female.

Temp. (°C.)	R.H. (%)	No. of pairs investi- gated	Pre- oviposi- tion period in days (Mean \pm S.E.)	Oviposi- tion period in days (Mean \pm S.E.)	Post- oviposi- tion period in days	No. of eggs laid (Mean \pm S.E.)	No. of eggs left in the ovaries (Mean \pm S.E.)
22 \pm 3	83 \pm 7	11	3.5 \pm 0.55	4 \pm 0.43	1	37 \pm 5.4	4.4 \pm 1.04
26.5 \pm 0.5	67 \pm 7	12	1.4 \pm 0.15	3.8 \pm 0.11	1	48 \pm 5.8	5.5 \pm 1.2

The correlation 'r' between the weight of the female and the number of eggs laid is 0.9651, which is highly significant. It shows that there is linear relation-ship between the weight of the female and the number of eggs laid. The fitted regression line $Y = 20963.61 \times -21.118$, together with the confidence belts, is shown in fig. 2.

TABLE XII.

Number of eggs laid by females of different weights.

Serial no.	Weight of the female on emergence (gm.)	No. of eggs laid
1	0.0014	17
2	0.0017	24
3	0.0020	14
4	0.0020	22
5	0.0021	24
6	0.0021	21
7	0.0024	8
8	0.0024	23
9	0.0024	28
10	0.0024	28
11	0.0025	29
12	0.0026	30
13	0.0027	31
14	0.0028	37
15	0.0029	34
16	0.0030	44
17	0.0033	54
18	0.0034	56
19	0.0035	58
20	0.0042	70
21	0.0051	83

Sex ratio.

In order to determine the sex ratio, the adults emerging from the cultures maintained in the laboratory at $26.5 \pm 0.5^{\circ}\text{C}$. and 70 ± 5 per cent. R.H. were examined. Out of 123 adults, 89 were females and 34 males. The sex ratio of female to male is, therefore, nearly 2.6:1.

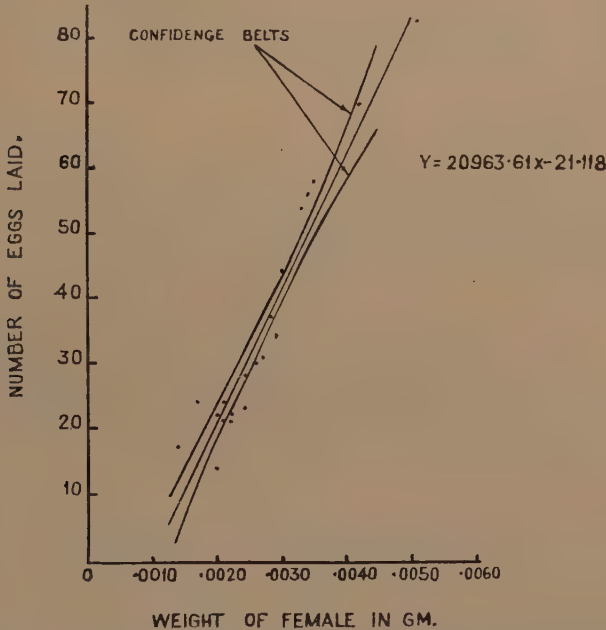


Fig. 2.—Relationship between the weight of female of *T. pellionella* at emergence and number of eggs laid.

Length of life.

The life-span of the male and female adults which were used for studies on oviposition (*cf.* Table XI) was investigated. The results are shown in Table XIII.

TABLE XIII.

Length of life of male and female adults.

Temp. (°C.)	R.H. (%)	No. of adults	Life-span in days	
			Male	Female
			Mean \pm S.E.	Mean \pm S.E.
22 ± 3	83 ± 7	11	4.4 ± 0.55	6.6 ± 0.8
26.5 ± 0.5	67 ± 7	12	3.5 ± 0.6	5.2 ± 0.28

Unmated females lived for 6 ± 0.5 days at $22 \pm 3^{\circ}\text{C}$. and 83 ± 7 per cent. R.H.

Relationship between the weight of the female at emergence and its life-span.

Freshly emerged normal females were weighed individually and then introduced separately in specimen tubes (4" × 1½") together with a freshly emerged normal male. The life-span of the females was recorded at $28.5 \pm 0.5^\circ\text{C}$. and 85 ± 5 per cent. R.H. and the length of life of 21 females weighing from 0.0017 to 0.0051 gm. varied between 3 and 8 days, but the correlation between the weight of the female and its life in days was not found to be significant.

In the case of the Brown House Moth, *Hofmannophila pseudospretella* (Stnt.), a significant correlation has been traced between length of life and the weight of the female at emergence (Woodroffe, 1951).

Number of Generations in a Year.

Generations of *T. pellionella* overlap, due to sensitivity of the larval stage to temperature and humidity conditions. There are 3 or 4 generations in a year at $26 \pm 8.0^\circ\text{C}$. and 82 ± 10 per cent. R.H. when the larvae are fed on woollen fabrics impregnated with 5 per cent. yeast.

Parasites.

The following species have been recorded as parasites of *T. pellionella*: *Apanteles carpatus* (Say), *A. riograndensis* Brèth., *Chremylus rubiginosus* (Nees), *Metacoelus mansuetor* (Grav.) (Thompson, 1947) and *Habrocytus sazesenii* (Ratz.) (Voukassovitch & Voukassovitch, 1931).

Summary.

Tinea pellionella (L.), commonly known as the Case-bearing Clothes Moth or Fur Moth, is of world-wide distribution and is of considerable economic importance. It has been recorded on a variety of substances, particularly those of a keratinous nature. In India, it has been found as an important pest of woollen textiles. Its life-history and habits have been systematically investigated at different levels of temperature and humidity.

The incubation period is 4 to 5, 5, 6 to 7 and 6 to 7 days at 21.5 , 25 , 30 and 32.5°C ., respectively. Temperatures higher than 32.5°C . have been found lethal to eggs. Humidity has no effect on the incubation period. Percentage viability of eggs is greater at lower than at higher temperatures.

Both temperature and humidity have been found to influence the larval development and the number of larval instars. Irrespective of temperature, higher humidities favour shorter larval development and the shortest larval period is at 25°C . and 90 per cent. R.H.

Woollen materials impregnated with yeast are more suited for the larval development than those not so treated. Larvae do not exhibit colour preference. Woollen fabrics dyed with *Cloth fast orange G 4 per cent.* manufactured by "Ciba", however, inhibit the growth of freshly hatched larvae.

The behaviour of the larvae to direct sunlight has been studied. The rôle of (a) diffused light alternated with darkness, (b) darkness, (c) temperature and (d) humidity on the extent of damage caused by the larvae has been investigated. Under the conditions of the experiments, the amount of damage in continuous darkness was significantly greater than in alternating light and darkness, and that at 90 per cent. R.H. significantly greater than at 30 per cent., but there was no significant difference in the amount of damage at 27.5° and 32.5°C ., respectively, and 90 per cent. R.H.

The mode of pupation has been described. The pupal period has been studied and found to occupy 18 ± 0.4 , 10.3 ± 0.16 and 10.3 ± 0.33 days at 21.5 , 25 and 30°C . and 90 per cent. R.H., respectively. Humidity has no effect on this period.

The effect of temperature and humidity on (a) the preoviposition, oviposition and postoviposition periods and (b) number of eggs laid by a female has been studied. The life-span of the male and female, the relationship between the weight of the female at emergence and fecundity (which was highly significant) on the one hand and length of life (which was not significant) on the other has also been investigated. Sex ratio between females and males has been found to be 2.6:1. Three to four generations in a year have been recorded at $26 \pm 8.0^{\circ}\text{C}$. and 82 ± 10 per cent. R.H. when the larvae are fed on woollen fabrics impregnated with yeast.

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References.

- BACK, E. A. & COTTON, R. T. (1931). The control of moths in upholstered furniture.—Fmrs' Bull. U.S. Dep. Agric., no. 1655, 32 pp.
- BRADLEY, J. D. (1950). On the occurrence of *Tinea columbariella* Wocke (Lep. Tineidae) in England, with a description of the species.—Entomologist, **83**, pp. 169–172.
- BRUNETEAU, J. (1930). Les teignes des vêtements.—Rev. Zool. agric., **29**, pp. 149–159.
- BURGESS, R. & POOLE, E. J. (1931). Observations on the susceptibility of animal fibres to damage by the larvae of two species of Clothes Moth, *Tineola biselliella* Hummel and *Tinea pellionella* L.—J. Text. Inst., **22**, pp. T141–T157.
- BUXTON, P. A. & MELLANBY, K. (1934). The measurement and control of humidity.—Bull. ent. Res., **25**, pp. 171–175.
- DYAR, H. G. (1890). The number of molts of Lepidopterous larvae.—Psyche, **5**, pp. 420–422.
- FLETCHER, T. B. (1920). Life-histories of Indian insects. Microlepidoptera. VIII. Tineidae and Nepticulidae.—Mem. Dep. Agric. India, Ent. Ser., **6**, pp. 181–196.
- HAYHURST, H. (1942). Insect pests in stored products.—2nd edn., 108 pp. London, Chapman & Hall.
- HERRICK, G. W. (1914). Insects injurious to the household and annoying to man.—470 pp. New York, Macmillan.
- JENKINS, C. F. H. (1944). Clothes Moths and Carpet Beetles.—J. Dep. Agric. W. Aust., (2) **21**, pp. 51–57.
- KEMPER, H. (1934). Ueber Hausmottenbekämpfung.—Z. GesundhTech. Städtehyg., **26**, pp. 317–330.
- KEMPER, H. (1935). Die Pelz- und Textilschädlinge und ihre Bekämpfung.—Kleintier u. Pelztier, **11**, pp. 123–187.
- MARLATT, C. L. (1915). The true Clothes Moths.—Fmrs' Bull. U.S. Dep. Agric., no. 659, 8 pp.

- MORLEY, C. (1930). Clothes Moths' parasite.—Trans. Suffolk Nat. Soc., 1, p. 101.
- PAPPENHEIM, E. (1938). Beitrag zur Kenntnis der Oberflächenstruktur von Motteneiern.—Z. hyg. Zool., 30, pp. 240-243.
- THOMPSON, W. R. Ed. (1947). A catalogue of the parasites and predators of insect pests. Section 1. Parasite host catalogue. Part 9. Parasites of the Lepidoptera (Q-Z), p. 580. Belleville, Ont., Imp. Bur. biol. Contr.
- VOUKASSOVITCH, H. & VOUKASSOVITCH, P. (1931). Sur la ponte des Hyménoptères parasites entomophages.—C. R. Soc. Biol., 107, pp. 695-697.
- WATANABE, C. (1932). Notes on Braconidae of Japan. III. *Apanteles*.—Insecta matsum., 7, pp. 74-102.
- WOODROFFE, G. E. (1951). A life-history study of the Brown House Moth, *Hofmannophila pseudospretella* (Staint.) (Lep. Oecophoridae).—Bull. ent. Res., 41, pp. 529-553.
- YAMADA, Y. (1940). On *Tinea pellionella* L. [In Japanese.].—Botyu Kagaku, no. 4, pp. 14-20. (Rev. appl. Ent., (A) 30, p. 12.)
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FIG. 1. Eggs of *T. pellionella* ($\times 16$).



FIG. 2. Left; larval case. Right; a fully grown larva showing dorsum of 1st thoracic segment divided into two dark plates by a longitudinal band ($\times 6$).

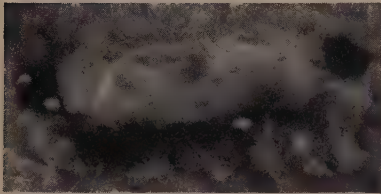


FIG. 3. Holes made by larva in fabric at either end of case, showing that larva can make a complete turn within the case without altering position of the case.

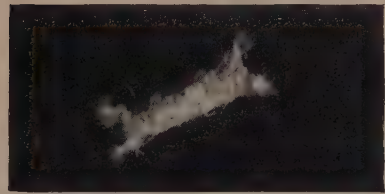


FIG. 4. Larval case attached, by means of silken threads at its corners, to a glass surface.



FIG. 5. Anterior half of pupal shell protruding from case after emergence of adult.



FIG. 6. A copulating pair of *T. pellionella*.

2
A STUDY ON THE IDENTITY OF *BRACON HEBETOR* SAY
AND *BRACON BREVICORNIS* WESMAEL
(HYMENOPTERA: BRACONIDAE).

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Bracon hebetor Say and *Bracon brevicornis* Wesm. are well-known ectophagous larval parasites of many Lepidoptera and are world-wide in distribution. A vast amount of literature has accumulated on various aspects of these parasites, including their taxonomy and synonymy. From a study of the literature, relating particularly to the taxonomy and host range of the species, it becomes doubtful whether these two species can be considered as distinct. The object of this paper is to review the position as it stands now (mainly from the Indian literature) and to present a few points in an attempt to clarify the confusion that exists in the determination of the species.

Host Range.

Richards & Thomson (1932) reviewed the host records of the two species, and it is interesting to note that, while giving the synonymy of *B. hebetor*, *B. brevicornis* was also included, though they considered the latter separately and regarded it as established "that *B. hebetor* is mainly a domestic species and *B. brevicornis* lives out of doors with of course a few exceptions in both cases". The following records of hosts for the two species, mainly from India, show more and more exceptions to the above general rule, and also throw some light on the confusion existing in the identity of the two species.

Bracon hebetor Say.

The various hosts of the species recorded in India both in nature and from rearings in the laboratory by previous workers are shown in Table I.

It is seen from Table I that *B. hebetor* has been recorded on a number of Lepidopterous insects in the field, in addition to a few "domestic" species, by various workers in different parts of India, and it has also been induced to take additional Lepidopterous hosts in the laboratory. Further, it is interesting to note that the species has also been recorded as a hyperparasite of an Ichneumonid (*Pristomerus testaceicollis* Cam.) parasitising the lac-predator, *Holcocera pulvereana* (Meyr.).

Bracon brevicornis Wesm.

Richards & Thomson (1932) gave a list of hosts recorded by several workers, assuming that *Bracon vernalis* Szépl., *B. kitcheneri* (Dudgn. & Gough) and *B. lefroyi* (Dudgn. & Gough) were synonymous with *B. brevicornis*. Unless this synonymy is established, the host records given for *B. brevicornis* by the above authors cannot be taken as entirely correct. The hosts recorded in India for the species are shown in Table II.

Here also, in addition to various field insects, at least two "domestic" species are included as hosts of *B. brevicornis* in India; the hosts recorded for this species elsewhere include more domestic species (Richards & Thomson,

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TABLE I.
Hosts of *Bracon hebetor* Say recorded from India.

In nature	In the laboratory	Place	Source
<i>Corecra cephalonica</i> (Stnt.)		South India	Krishna Ayyar (1934)
<i>Eublemma amabilis</i> (Moore)			Glover & Chatterjee (1936)
<i>Eublemma scitula</i> (Ramb.)		North India	
<i>Holocera pulverece</i> (Meyr.)			Sen (1937)
<i>Hieromantis icorysta</i> Meyr.		Namkum (North India)	
<i>Tonica niviferana</i> (Wlk.)			
<i>Pristomerus testaceicollis</i> Cam.			
<i>Antigstra catalaunalis</i> (Dup.)	<i>Platyedra gossypiella</i> (Saund.)	Delhi (North India)	Ghulam Ullah (1939)
<i>Phthorimaea operculella</i> (Zell.)	<i>Earias fabia</i> (Stoll)		
<i>Laphygma</i> sp.	<i>Earias insulana</i> (Boisd.)	Coimbatore (South India)	Cherian & Kylasam (1941)
<i>Earias fabia</i> (Stoll)			
<i>Antigstra catalaunalis</i> (Dup.)		Bihar (North India)	Negi, Venkatraman & Chatterjee (1944)
<i>Laphygma</i> sp.		Delhi (North India)	
<i>Antigstra catalaunalis</i> (Dup.)		South India	
<i>Corecra cephalonica</i> (Stnt.)	<i>Holocera pulverece</i> (Meyr.)	North India	Negi, Venkatraman & Chatterjee (1944)
<i>Adisura atkinsoni</i> Moore	<i>Eublemma amabilis</i> (Moore)		
	<i>Ephestia cautella</i> (Wlk.)		
	<i>Platyedra gossypiella</i> (Saund.)		
	<i>Corecra cephalonica</i> (Stnt.)		
	<i>Corecra cephalonica</i> (Stnt.)	Bangalore (South India)	Krishnamurti & Seshagiri Rao (1944)
		India	Thompson (1945)
	<i>Adisura atkinsoni</i> Moore	Bangalore (South India)	Krishnamurti & Appanna (1948)
	<i>Sesamia inferens</i> (Wlk.)	Bangalore (South India)	Usman & Krishnamurti (1950)
	<i>Stenachroia elongella</i> Hmps.		Appanna (1953)
	<i>Phthorimaea operculella</i> (Zell.)	Bangalore (South India)	
	<i>Argyria sticticrasis</i> Hmps.		

TABLE II.

Hosts of *Bracon brevicornis* Wesm. recorded from India.

In nature	In the laboratory	Place	Source
<i>Corcyra cephalonica</i> (Stnt.)	<i>Adisura atkinsoni</i> Moore <i>Antigastra catalaunalis</i> (Dup.) <i>Laphygma</i> sp. <i>Phthorimaea operculella</i> (Zell.) <i>Platyedra gossypiella</i> (Saund.) <i>Earias fabia</i> (Stoll.) <i>Earias insulana</i> (Boisd.)	Bangalore (South India) Delhi (North India)	Krishnamurti & Appanna (1944) Lal (1947)
<i>Noorda moringae</i> Tams <i>Nepantis serinopa</i> Meyr. <i>Ephesia cautella</i> (Wlk.) <i>Phycita infusella</i> (Meyr.) <i>Earias insulana</i> (Boisd.) <i>Sesamia cretica</i> (Led.)		India	Ramchandra Rao, Cherian & Ananthanarayanan (1950)
<i>Adisura atkinsoni</i> Moore		Bangalore (South India)	Krishnamurti & Appanna (1948)
<i>Heliothis armigera</i> (Hb.) <i>Agrotis</i> sp. <i>Nephopteryx</i> sp.		India	Thompson (1953)
<i>Chilo zonellus</i> (Swinh.)		India	Narayanan, in discussion (Bowden, 1954)

1932). A comparative study of the hosts recorded for the two species exhibits close similarity and gives rise to doubt as to whether, in India at least, two species are involved.

Morphological Characters.

Various morphological characters have been taken into consideration in distinguishing the two species. Richards & Thomson (1932), Cherian & Margabandhu (1949) and various other workers have definitely stated that there is a wide range of colour variation in both species. Richards & Thomson came to the conclusion that "differences in colour are of almost no value in defining species". The next point to be considered is the number of antennal joints. Recently, Lal (1947) after reviewing the position and basing his observations on the key given by Muesebeck (1925) in the identification of *B. hebetor* and *B. brevicornis*, stated that "the specimens reared and identified at Namkum-Ranchi (North India) as *hebetor* have all 13- to 15-segmented antennae in the female and 18 to 23 in the male. The flagellar segments both in the female and the male, are very little longer than broad. In most of the specimens the abdominal tergites are smooth and shining rather than punctate. These specimens are typically *hebetor*". He further observed that there were considerable intraspecific variations in both species in respect of not only body colour and the number of antennal joints but also in the nature of punctation on the abdominal tergites and the relative proportions of the lengths of flagellar joints. He also found that, in several specimens examined by him, whereas the abdominal punctation brought them close to *brevicornis*, the number of antennal joints corresponded to *hebetor*. In spite of these variations, he came to regard the parasites as specifically distinct, identifiable by Muesebeck's key with, however, the modification "that the antennal segments in the female of *brevicornis* may range from 16 to 21". He also indicated that the two species "may turn out to be identical with perhaps tolerably well defined biological or, what is more likely, geographical races".

Cherian & Margabandhu (1949), mainly relying on the analysis of Cushman (1922) who had "the advantage of having Wesmael's description of *brevicornis*, Marshall's specimens from Britain, specimens in the United States National Museum and the ones from Europe from the European corn borer", based their conclusions entirely on the number of antennal joints and stated that the two species could be distinguished on this factor. They, however, were not clear on the range of variation in the number of antennal joints for *hebetor* and *brevicornis* though they considered the female having 16-jointed antennae to be *hebetor*.

Observations and Discussion.

A large number of specimens of *B. hebetor* reared from *Corcyra cephalonica* (Stnt.) and *Ephestia cautella* (Wlk.) in the insectary were examined in detail for (a) variations in colour, (b) number of antennal joints, (c) the relative lengths of flagellar joints in the antennae and (d) the punctation on the abdomen, besides general observations on the shape and size of the body, length of ovipositor, etc. Another batch of specimens collected in food-grain godowns at various times around Bangalore was also examined for the same characters. A series of 16 specimens of *B. brevicornis* reared on *Nephantis serinopa* Meyr. at Coimbatore (South India) was received and examined for all the above characters. A batch of 4 specimens (males) of *B. brevicornis* reared on the European Corn Borer, *Pyrausta nubilalis* (Hb.), and received from Moorestown, New Jersey, U.S.A., another group of six alcohol-preserved specimens (4 females and 2 males) of the same species received from Canada, and a large number of parasites reared in the laboratory at Bangalore on *C. cephalonica* and *E. cautella*

and determined by Dr. Ch. Ferrière in 1930 and Mr. G. E. J. Nixon in 1952 as *B. brevicornis* have been examined. In addition, 150 specimens of *B. brevicornis* received from the Indian Agricultural Research Institute, New Delhi, were also examined. A comparative study of the female genitalia (external) of a number of *B. hebetor* and *B. brevicornis* specimens was made in order to establish whether these two species are synonymous or distinct. Finally, attempts were made to cross *B. brevicornis* received from Delhi and *B. hebetor* reared in the laboratory here with complete success.

The belief that *B. brevicornis* is mostly a parasite of field insects and *B. hebetor* a parasite of stored product insects (Cherian & Margabandhu, 1949; and others) cannot be entirely relied upon as the host records given above show that both species have been, in some cases, reared from the same hosts. Colour variations were found to be common in both species. As regards punctuation on the abdomen, the majority of the specimens examined in both species showed a "smooth" abdomen very faintly reticulated on the dorsal surface, shining and sparsely hairy, while a few specimens in one and the same lot could, however, be seen to have fine punctuation on the abdomen. With regard to the relative proportions of the length and widths of the flagellar joints in the antennae, the female specimens agreed with the characters given for *hebetor* by Lal (1947) and the male specimens tallied with those given for *brevicornis* by Muesebeck, in both species. Further, regarding the relative proportions of lengths of the flagellar joints, the majority of specimens of both sexes in the two species showed that the first flagellar joint was only a little longer than or in a few cases equal in length to the second, agreeing with the condition in *brevicornis* given by Muesebeck.

Having considered all the minor taxonomic characters, the next point to be considered is the number of antennal joints which previous workers have taken as the main and decisive basis for the separation of the two species. At the outset, it is necessary to assess how far the number of antennal joints is valid as a character for the separation of the two species. The authors (1952) in a separate paper have reported that variation in the number of joints of the two antennae of the same specimen of *hebetor* is quite common, the difference in most cases being one joint. This feature vitiates the very basis for separating the two species, as, for example, a specimen having a 15-jointed antenna on one side and 16 on the other (which is quite common) would be identified as *hebetor* on counting the antennal joints of one side and as *brevicornis* on counting those of the other side. Similar variation is also to be seen in specimens of *brevicornis* examined.

That there is confusion in the identity of at least the Indian specimens is quite clear from the records of Cherian & Margabandhu (1949) who considered females with 16-jointed antennae to be *hebetor* and of Lal (1947) whose key for *brevicornis* gave the range from 16 to 21 antennal joints in the female. To add to this, the former authors stated that they received from the then Imperial Entomologist, Delhi, two female specimens with 15- and 16-jointed antennae, named as *hebetor* by Lal himself, according to whom the female with 16-jointed antennae ought to have been grouped under *brevicornis*.

Further, Lal (1947) has recorded his observations on the number of antennal joints of a number of sets of parasites reared on different hosts in an attempt to clarify the position of the two species. His observations on the progeny of a pair of parents attacking *A. catalaunalis* are very interesting. All the specimens of the progeny, the females of which showed 16- to 21-jointed antennae, were considered by Lal to be *brevicornis*. But this simple position became complicated and confused when, as reported by Lal himself, Mr. Nixon of the Commonwealth Institute of Entomology identified from specimens from the same lot as the above, two as belonging to *B. hebetor* (one female with 14-jointed antennae,

TABLE III.
Counts of antennal joints in females and males of *B. hebetor* and *B. brevicornis*.

Parasite	Host and place	No. of parasites examined	% of females with antennae having joints					% of males with antennae having joints									
			13	14	15	16	17	16	17	18	19	20	21	22	23	24 and above	
<i>Bracon brevicornis</i>	..	190	—	4	34	62	—	—	—	7	15	15	21	39	3	—	
"	<i>Corcyra cephalonica</i> (Stnt.) Bangalore (South India)	6	—	—	—	—	100	—	—	—	—	—	25	—	—	75	
"	<i>Pyrausta nubilalis</i> (Hb.) Canada	16	—	—	—	60	40	—	—	—	—	—	57	43	—	—	
"	<i>Nephanthis sertuopa</i> Meyr. Coimbatore (South India)	150	—	—	10	70	20	2.3	2.3	2.3	2.3	11.4	13.5	38.5	18.4	9	
<i>Bracon hebetor</i>	Cotton bollworms? Delhi (North India)	32	—	60	—	40	—	—	4	8	23	23	27	8	7	—	
"	<i>Ephestia cautella</i> (Wlk.) .. Bangalore	82	5	34	42.5	18.5	—	—	2	11.5	13.5	23	32	13.5	4.5	—	
"	<i>Corcyra cephalonica</i> (Stnt.) Mandya (South India)	168	2.5	5	53	37	2.5	—	2	—	6.5	15	44.5	22.5	9	—	
"	Food-grain godowns .. Bangalore	46	7.5	15	70	7.5	—	—	—	20	—	10	30	40	—	—	
"	<i>Adisura alkinsoni</i> Moore Bangalore	228	—	12.5	48	39.5	—	—	—	4	16	36	20	20	4	—	
"	<i>Corcyra cephalonica</i> (Stnt.) Bangalore	114	—	26.5	42.5	31	—	1.5	5.5	13.5	13.5	17	22.5	26.5	—	—	
Progeny of pairs of parents the females of which had 15-jointed antennae	"	24	—	18.5	25	56.5	—	12.5	—	25	12.5	25	25	—	—	—	
" 15/16-jointed antennae	"	202	—	23	54	23	—	—	4	—	7	22.5	22.5	42.5	1.5	—	
Progeny of <i>B. hebetor</i> male × <i>B. brevicornis</i> female	"	60	—	—	—	100	—	—	—	—	—	3.5	26	52	18.5	—	
Progeny of <i>B. brevicornis</i> male × <i>B. hebetor</i> female	"	74	4.5	36	50.5	9	—	6.5	—	13	20	40	26.5	—	—	—	

and one male with 20-jointed antennae) and the other two as *B. stabilis* Wesm. which Lal took to be very near *B. brevicornis*. Though two species have been recognised in the progeny of the same pair of parents, it is obvious that there can be no two species involved.

The observations made on the number of antennal joints of different sets of specimens reared here and those received from other places are summarised in Table III. In the case of parasites showing variation in the number of antennal joints in the same specimen, the antenna showing the lower number of joints was taken into consideration.

It is clear from the data given in Table III that the number of antennal joints, hitherto considered as the main distinguishing character of the two species, does not help in distinguishing the two but that, on the other hand, the range of variation indicates that there is only one species.

An examination of the male and female genitalia of a number of specimens of *hebetor* and *brevicornis* (inclusive of those reared on *Pyrausta* and *Nephantis*) revealed almost no distinct difference between the two species.

Finally, attempts were made to cross individuals of the two species and the results have been published elsewhere (Puttarudraiah & Channa Basavanna, 1954). Unmated males and females of *B. hebetor* reared on *Corcyra* in Bangalore were enclosed separately along with individuals of the opposite sex of unmated *B. brevicornis* received from Indian Agricultural Research Institute, Delhi. It was found that mating between the opposite sexes of the two species, egg-laying by the females, larval and pupal development and finally emergence of adults were normal in all cases. The progeny of both series of crosses, namely *B. hebetor* female \times *B. brevicornis* male and *B. brevicornis* female \times *B. hebetor* male, were found to be fertile both when inbred and when crossed with pure *hebetor* and *brevicornis*.

The above observations on the morphological characters including male and female genitalia and the experiments on the interbreeding of the two species show that, as far as Indian specimens are concerned, at least, only one species is involved and its valid name is *hebetor* Say. As regards specimens from Europe and other countries, it is felt that a comparative study of the different morphological characters of a large number of specimens, as well as interbreeding tests, are necessary before it can be established whether two species really exist or whether *brevicornis* is a synonym of *hebetor*.

Summary.

Literature, mainly Indian, pertaining to the recorded hosts of *Bracon hebetor* Say and *B. brevicornis* Wesm., and on the taxonomy of the two species, has been reviewed. Observations on different morphological characters, including the male and female genitalia, which have been used in establishing the identity of the two species, have been made. A large number of *B. hebetor* specimens reared in Bangalore on *Corcyra cephalonica* (Stnt.), *Ephestia cautella* (Wlk.), *Adisura atkinsoni* Moore and those collected in food-grain godowns, and of *B. brevicornis* reared on *C. cephalonica* and *E. cautella* in Bangalore, on *Nephantis serinopa* Meyr. from Coimbatore (South India), on *Pyrausta nubilalis* (Hb.) from Canada and on cotton bollworms (?) from Delhi (North India), have been examined.

Differences in colour, relative proportions of antennal joints and punctuation on the abdomen have been found to be variable and as such are not to be depended upon for distinguishing the two species. The number of antennal joints which has hitherto been considered to be the decisive character by which the two species may be separated is also not reliable as there is a wide range of variation even in the progeny of a single pair of parents. Above all, the fact that the two species interbreed and give rise to fertile offspring, which also show a

fairly wide range of variation in the number of antennal joints, proves that the two are identical, and there is no ground to treat them as two distinct species, at least so far as the Indian specimens are concerned, for which *Bräcon hebetor* Say is the valid name.

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References.

- APPANNA, M. (1953). Indian J. Ent., **14**, pp. 263-267.
- BOWDEN, J. (1954). Rep. 6th Commonw. ent. Conf. 1954, pp. 104-107 (discussion, pp. 107-110).
- CHERIAN, M. C. & KYLASAM, M. S. (1941). Proc. Indian Acad. Sci., (B) **14**, pp. 517-528.
- CHERIAN, M. C. & MARGABANDHU, V. (1949). J. Bombay nat. Hist. Soc., **48**, pp. 335-337.
- * CUSHMAN, R. A. (1922). Proc. ent. Soc. Wash., **24**, pp. 122-123.
- GHULAM ULLAH (1939). Indian J. Ent., **1**, pp. 111-112.
- GLOVER, P. M. & CHATTERJEE, K. C. (1936). Proc. Indian Acad. Sci., (B) **3**, pp. 195-211.
- KRISHNA AYYAR, P. N. (1934). Bull. ent. Res., **25**, pp. 155-169.
- KRISHNAMURTI, B. & APPANNA, M. (1944). Curr. Sci., **13**, p. 135. *
- KRISHNAMURTI, B. & APPANNA, M. (1948). Bull. agric. Coll. Mysore, Ent. Ser. no. 13, 16 pp.
- KRISHNAMURTI, B. & SESHAGIRI RAO, D. (1944). Curr. Sci., **13**, pp. 81-82.
- LAL, K. B. (1947). Indian J. Ent., **8**, pp. 85-88.
- * MUESEBECK, C. F. W. (1925). Proc. U.S. nat. Mus., **67**, pp. 1-85.
- NEGI, P. S., VENKATRAMAN, T. V. & CHATTERJEE, K. C. (1944). Curr. Sci., **13**, p. 136.
- PUTTARUDRIAH, M. & CHANNABASAVANNA, G. P. (1952). Nature, **169**, p. 378.
- PUTTARUDRIAH, M. & CHANNA BASAVANNA, G. P. (1954). Curr. Sci., **23**, p. 231.
- RAMCHANDRA RAO, Y., CHERIAN, M. C. & ANANTHANARAYANAN, K. P. (1950). Indian J. Ent., **10**, pp. 205-247.

* Not seen in original.

- RICHARDS, O. W. & THOMSON, W. S. (1932). Trans. ent. Soc. Lond., **80**, pp. 169-250.
- SEN, H. K. (1937). Rep. Indian Lac Res. Inst. Namkum 1936-37, pp. 12-22. (Rev. appl. Ent., (A) **25**, p. 635.)
- THOMPSON, W. R. *Ed.* (1945). A catalogue of the parasites and predators of insect pests . . . Section 1. Part 6, p. 219. Belleville, Ont., Imp. Parasite Serv.
- THOMPSON, W. R. *Ed.* (1953). *Ibid.*, Section 2. Part 2, p. 140. Belleville, Ont., Commonw. Bur. biol. Contr.
- USMAN, S. & KRISHNAMURTI, B. (1950). Curr. Sci., **19**, p. 155.
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INSECTICIDAL FOGS AGAINST TSETSE FLIES ON TRAINS.

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L.F.

Lewis (1950) has described in detail the special trypanosomiasis problem created in Kenya by the Mombasa-Nairobi railway. For many miles the line passes through bush infested with tsetse flies, and Lewis showed conclusively that trains carry an astonishing number of flies well beyond the fly-belts, causing trypanosomiasis on farms that would otherwise be free of this disease. He discusses several ways of dealing with the problem, including bush-clearing on the affected farms, bush-clearing or native settlement alongside the railway, and the "de-flying" of trains. Amongst methods of removing flies from trains are hand-catching, internal spraying with insecticidal aerosols, external coarse sprays (possibly applied by a modified carriage-washing apparatus) and insecticidal fogs.

Hand-catching, by means of fly-boys who search the insides of passenger coaches and the outsides of goods wagons, has been carried out at Sultan Hamud station (Lewis, 1950, map 1) since 1946. But it is clear that the fly-boys can never catch more than a proportion—perhaps two-thirds—of the tsetse flies present; and such work, while no doubt alleviating the problem, is more important in providing a continuous index of its magnitude. During 1951, tests with coarse external sprays from ordinary knapsack sprayers were carried out by the writer with some success, but the cost was prohibitive. Earlier, insecticidal fogs had been tried in conjunction with an improvised tunnel erected near Kiboko station; as the trains slowly left the station the tunnel was filled with fog from a special machine.* The results were not very satisfactory and the method was very expensive.

Expense, indeed, is the essence of the problem of destroying tsetse flies carried by trains. For reasons which need not be gone into here, the incidence of trypanosomiasis in the affected farms (Lewis, 1950, map 2) has declined during the past eight years, and has now reached a point where control by drugs is in every way feasible. Any method of "de-flying" trains, therefore, which costs more than therapeutic control has little practical value. Under such a limitation it seemed for a time that no economical method would be found. In 1953, however, the new machine described below offered a chance of producing insecticidal fogs more cheaply than before, and the present experiments were accordingly carried out.

The machine † is a portable fog generator operating on the pulse-jet principle, that is to say, with no moving parts. A series of fuel-air mixtures are fired in a special combustion chamber, thus creating high-velocity waves of hot gas in an exhaust pipe. Fluid containing an insecticide is injected under pressure into the exhaust pipe and is emitted as a dense fog. The machine is started by connecting it for about half a minute to a six-volt battery that heats a glow-plug in the combustion chamber. Once started, the battery is disconnected and the machine runs by itself until the fuel—one quart of petrol—is exhausted. This takes about an hour and uses up two gallons of insecticidal fluid. The insecticide tank holds only one gallon but can be re-filled without stopping the machine.

During the experiments described below, some mechanical difficulties came to light, chiefly in the insecticide supply system, where the numerous jets and

* The "Todd Insecticidal Fog Applicator."

† The "Swingfog Pest Control Unit."

filters tended to get blocked. The insecticidal solvent used was a proprietary high-quality kerosene,** which readily dissolved 15 per cent. DDT and seemed to produce a better fog than either Diesoline or ordinary kerosene.

Experimental Layout.

In order not to dislocate timetables, it was necessary to select, for fogging operations, a station at which trains invariably stopped. This gave a choice of Makindu (Lewis, 1950, map 1), which is twenty miles inside a fly-belt, or Sultan Hamud, which is twenty miles outside. It would have been illogical not to protect the first twenty miles outside a fly-belt (into which the bulk of flies are shed), especially in the present case where these included an important grazing scheme, and Makindu was therefore chosen for fogging, despite the risk that flies might be picked up in the light infestation beyond. The effects of fogging were measured by catching at Sultan Hamud, forty miles nearer to Nairobi.

The catches in the experiments described below consisted entirely of *Glossina longipennis* Corti with the exception of four *G. pallidipes* Aust. and one *G. brevipalpis* Newst.

At Makindu, two machines and two African operators were used, only goods trains were fogged, and the average time needed for each train was ten minutes. As soon as a train stopped, one operator started on one side at the engine and moved rearwards, the other operator started on the opposite side at the brake van and moved forwards. In this way it was hoped to trap between two palls of fog any flies obstinately attached to the train. The machines were moved up and down so that every part of the wagons was enveloped in fog, which dispersed quickly from the sides but lingered underneath in the favourite settling places of tsetse flies.

First Fogging Experiment.

This covered fifteen days, from 22nd October to 5th November 1953. Trains were fogged on alternate days only, the other days being used as controls, except that on the last day four trains were fogged and two were left as controls. The insecticide mixture contained 15 per cent. DDT and 0.05 per cent. pyrethrum. Catches at Sultan Hamud are shown in Table I.

TABLE I.

First fogging experiment. Tsetse flies caught on trains at Sultan Hamud.

	Days	Trains	Total flies	Mean flies per train	S.E. mean
Fogged	8	28	23	0.8	$\pm .20$
Not fogged	8	38	127	3.3	$\pm .74$

The mean catches are significantly different ($P < .01$) and the reduction achieved by fogging was 75 per cent., with fiducial limits 30 to 100 per cent. (Catches on trains are very variable, and it is not possible to obtain precise estimates of the effect of fogging without very lengthy tests.) It should be noted that catches at Sultan Hamud include any flies that may have boarded trains after fogging at Makindu, and therefore the actual kill due to insecticide was if anything higher than the "reduction" observed.

** Sovacide F.

Second Fogging Experiment.

This experiment was in two parts. In the first part, from 6th to 12th November 1953, all trains were fogged every day with the same insecticide mixture as in the first experiment. Then for the next seven days all trains were fogged with the same mixture, omitting the pyrethrum. The results are shown in Table II. It is obvious that the reduction in numbers is quite unaffected by the presence or absence of pyrethrum, despite its well-known knockdown effect.

TABLE II.

Second fogging experiment. Tsetse flies caught on trains at Sultan Hamud.

	Days	Trains	Total flies	Mean flies per train	S.E. mean
DDT and pyrethrum ..	7	30	44	1.5	$\pm .36$
DDT only	7	23	31	1.3	$\pm .36$
Combined result ..	14	53	75	1.4	$\pm .26$

An adequate control for the combined result is difficult to find. Comparing it with the control figure from the first experiment gives a reduction of 58 per cent., with fiducial limits of 10 to 100 per cent., which is just significant ($P < .05$). This test assumes, however, that there is little variation in catches from one week to another, which is not so: investigation showed that the number of flies found on trains varies considerably from week to week. We can only legitimately compare the combined result for two weeks with the mean of eight earlier weeks in which no fogging took place, as shown in Table III.

TABLE III.

Assessment of second fogging experiment.

	Weeks	Weekly mean flies per train	S.E. mean
Fogging	2	1.4	$\pm .06$
No fogging ..	8	3.7	$\pm .52$

According to the data presented in Table III the reduction achieved for two weeks was 62 per cent., and using the t test with Bessel's correction, P is just over 0.05. Thus both tests give much the same answer, namely, a reduction of about 60 per cent. due to fogging.

During the first week of the second experiment, one train was not fogged owing to heavy rain at Makindu; 24 flies were caught on it at Sultan Hamud. During the second week, one train was deliberately not fogged; it produced a catch of 34 flies at Sultan Hamud, more than the whole week's collection from 23 fogged trains. There can be no doubt of the real effect of fogging, though these striking catches also illustrate the wide variation that is found from train to train.

Costs.

On the average, one train required two pints of insecticide. At local prices the total cost of fogging was approximately three shillings a train. A reasonable estimate of the average number of trains is five daily, or say two thousand a year. The cost of fogging these would be £300, excluding the initial cost of two Swingfog machines (£170), a battery (£8) and a charging plant (£35), and replacements and operators' wages, all of which would bring the annual cost into the region of £1,000. As far as can at present be ascertained, this is considerably more than the therapeutic control of trypanosomiasis would cost.

Summary.

Experiments were carried out in Kenya to find whether insecticidal smokes from "Swingfog" machines would remove tsetse flies, in this instance almost all *Glossina longipennis* Corti, carried by trains. Fogging was done by two operators, each with a machine, starting from opposite ends of trains halted at a station twenty miles inside a fly-infested area and assessment was by routine catches at a station twenty miles outside it. It was found that fogging reduced the number of flies found on trains by 60 to 70 per cent. As the trains had to pass through a light fly infestation after fogging, the real kill is likely to have been higher. The cost of such partial reduction is believed to be considerably higher than would be that of therapeutic control of trypanosomiasis in the affected region.

Acknowledgements.

I am indebted to Dr. P. E. Glover, Chief Field Zoologist, who suggested this work, for advice and assistance; to Mr. E. F. Whiteside, for statistical tests and criticism of the manuscript; and to the Director of Veterinary Services, Kenya, for permission to publish this paper.

Reference.

- LEWIS, E. A. (1950). Tsetse flies carried by railway trains in Kenya Colony.—*Bull. ent. Res.*, **40**, pp. 511–531.
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THE STABILITY OF A DDT SUSPENSION.¹

By W. B. HAWKINS and C. W. KEARNS²

Several workers have reported upon the loss of DDT from an aqueous colloidal suspension. Cutkomp (1947), while studying the thermal decomposition of DDT, found that aerated and aged dispersions of DDT showed no chemical change of the DDT. He reported, however, that a portion of the DDT had settled out to the bottom of the glass container. He stated that when this settling out occurred, the dispersion would be less toxic to any organism introduced.

Upholt (1947) investigated the residual toxicity of DDT suspended in water. He compared the period of effectiveness of suspensions in glass dishes, when alone, and when stream mud was present. The DDT suspensions in glass soon lost their toxicity to mosquito larvae. In the presence of the mud, the killing action of the suspensions persisted for even less time. Upholt suggested that the organic portion of the mud was, in part, responsible for inactivating the DDT.

In this laboratory, Krusé, Ludvik & Hawkins (1952) carried out work to identify some factors influencing the results of larval bioassays. One of the factors they believed to be responsible for their erratic larval kills was the undesirable flocculation of the DDT in the suspensions. They reported that a DDT-xylene-Trex emulsion was more stable than a suspension of DDT dispersed from ethanol. The DDT settled out more rapidly from each dispersion in cardboard cartons than in either glass or enamelled containers.

Since foreign ions in aqueous suspensions are most likely to be the cause of the undesirable flocculation, it was suggested (J. R. Lehr, private communication) that a picture of the ionic environment of the sol was necessary to the definition of the flocculation problem. An electrophoretic study of a DDT sol was considered the best way to gain this information. Spectrographic analyses of the different materials were also proposed. It was hoped that these analyses would show if ions were associated with the flocculated DDT and if so their possible source. Lastly, it was hoped that a correlation between larval kill and flocculation rate could be found. Should this not be found, then undoubtedly flocculation was not a factor influencing kill. The work reported upon here was undertaken in an effort to learn the cause and effect of flocculation in a DDT larvicidal suspension.

Materials and Methods.

No special effort was made to purify the materials used, since the purpose of this study was to characterise the conditions existing in a routine bioassay. The DDT (m.p. 107–109°C.) was recrystallised from a technical grade sample. The BaCl_2 and ThCl_4 were C.P. grade, and the KCl and AlCl_3 were A.C.S. Reagent grade. Pure ethyl alcohol of commerce and N.F. grade acetone were redistilled before use.

Cylindrical containers, about 90 mm. in diameter, constructed of pyrex glass, enamelled metal and cardboard were used. The pyrex glass dishes and enamelled cups were thoroughly washed and rinsed between uses. The cardboard ice-cream cartons were discarded after a single use.

The electrophoretic mobility measurements were made by the macroscopic

¹ This work forms part of a thesis by W. B. Hawkins (now at Division of Health and Safety, Tennessee Valley Authority, Wilson Dam, Alabama), approved by the University of Illinois for the degree of M.S.

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moving boundary method. The apparatus was similar to that described by Price & Lewis (1933). The potential applied at the main electrodes and across the U-tube was checked throughout each test with a voltmeter, and by means of a potentiometer was increased or decreased as necessary to maintaining the desired voltage. The U-tube was immersed in a water bath in which the temperature was maintained at $30 \pm 0.05^\circ\text{C}$.

In order to have a sol exhibiting an easily observed Tyndall effect, all suspensions used in the mobility work contained 500 μg . p,p' DDT per 100 ml. of aqueous dispersion. The DDT was dispersed from 1 ml. of ethanolic solution. Good layering and migration of the DDT sols were obtained when the supernatant liquid was 4 per cent. ethanol.

The suspensions of DDT were conditioned for 30 minutes in various concentrations of each of the four electrolytes—KCl, BaCl_2 , AlCl_3 , and ThCl_4 . The mobility measurements were then made. The conditioning times for other tests will be given in the section on results.

Twenty five grammes of the p,p' DDT as an acetone suspension were distributed among 65 cardboard cartons and conditioned for one hour. The suspensions were then poured into large pyrex glass crystallising dishes, the water evaporated off, and the DDT collected. The DDT was then ashed in a silicon dish to decompose the organic constituents. A spectrographic analysis, according to the method of

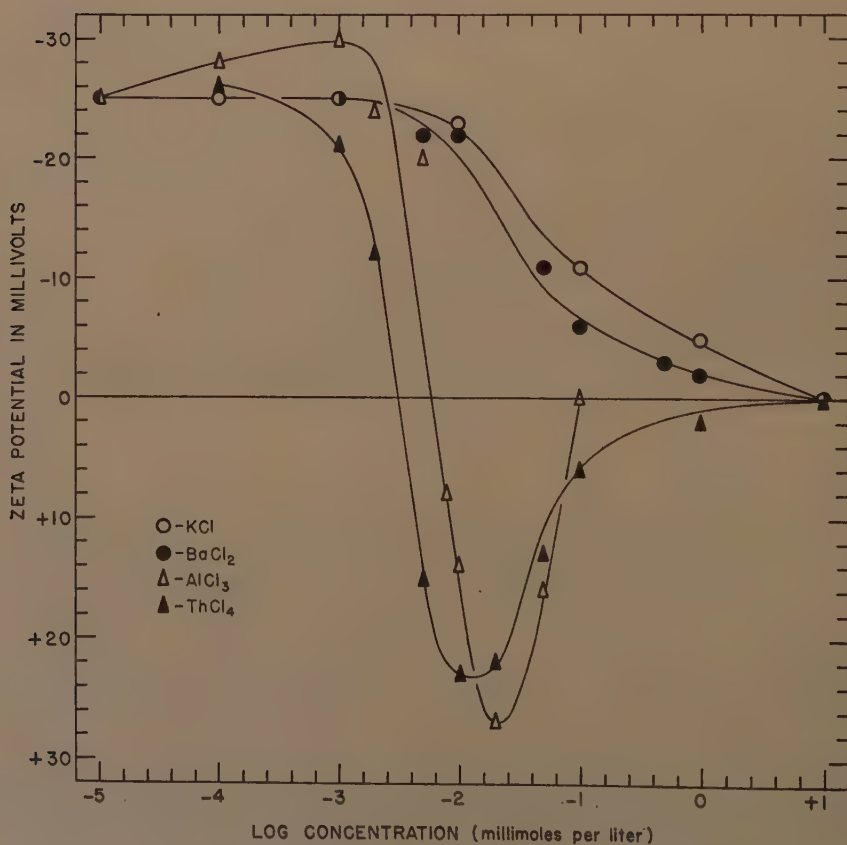


Fig. 1.—Effects of four electrolytes on the zeta potential of a DDT sol.

Slavin (1938), was made of the residue to determine the elements present. A sample of the reagent p,p'DDT and a paper carton were ashed and analysed in the same manner.

Tests were carried out with larvae of *Anopheles quadrimaculatus* Say that were reared in the insectary according to the method of Crowell (1940). Early fourth-instar larvae were chosen at random from the rearing pans and transferred to each DDT test suspension with a small wire loop. One hundred millilitres of a distilled water suspension or control solution were always used in each test container. As in the mobility tests the DDT was dispersed from 1 ml. of ethanolic solution. Control solutions contained one per cent. ethanol. The tests were conducted at a temperature of $77 \pm 2^\circ\text{F}$. Mortality counts were made after 24 hours, and those larvae were considered dead which did not move upon being touched. The kills were corrected for control mortality by the formula of Abbott (1925):

Results.

Electrophoretic measurements.

The zeta charge of DDT suspensions held in cardboard cartons was found to be zero, regardless of the time of conditioning. Conversely, sols held in glass or enamel containers possessed a charge of about -25 mv. up to 48 hours.

The cardboard cartons had a light wax coating, and it was suggested that the wax might be causing flocculation of the sols. Our results did not bear out this belief. The zeta potential of a DDT sol conditioned for 30 minutes in glass and enamelled containers coated with a household paraffin wax was found to be about -25 mv., the same as in unwaxed containers. However, after one hour in the waxed cardboard carton with an added coating of the household wax, the zeta was still -6 mv.

After recording these results, it seemed desirable to find the degree to which mono-, di-, tri-, and tetravalent ions were capable of depressing the zeta potential. The zeta potentials of the DDT sol after 30-minute exposures to various concentrations of KCl, BaCl₂, AlCl₃, and ThCl₄ are graphically illustrated in fig. 1. It can be seen that with KCl and BaCl₂, the zeta was depressed only to zero and at a log concentration of $+1$. With AlCl₃ and ThCl₄ the isoelectric point is reached at much lower concentrations of the electrolytes—about log concentration -2.2 for AlCl₃ and -2.5 for ThCl₄. The sign of the sol's zeta charge then reverses to positive and increases with electrolyte concentration to a positive potential of approximately the same magnitude as the maximum negative potential. The AlCl₃ then rapidly depresses the zeta charge to zero at log concentration -1 . ThCl₄ is rather less precipitous in its action and depresses the zeta potential to zero at log concentration $+1$.

Spectrographic analyses.

A weighed sample of the reagent p,p'DDT was ashed and the residue analysed spectrographically. The ash, 0.01 per cent. by weight of the original sample, contained Al, Ca, Fe and Mg as well as silicon. The ashing dish is believed to have been the source of the silicon found with this sample of p,p'DDT. When one of the cardboard cartons was decomposed in the same way, 3.1 per cent. remained as ash. The ash contained large amounts of Al and Si, and smaller amounts of Ca, Cu, Mg, Ba, Cr and Na. Titanium, the matrix constituent of the carton, was found in so large an amount as to be unestimable. A sample of the p,p'DDT conditioned in 65 cardboard containers yielded on ashing 0.68 per cent. ash. All the elements found in both the untreated DDT and the cardboard carton were present, plus four additional ones, Mn, Pb, Sr and Ag. These data are presented in detail in Table I.

TABLE I.

Quantitative spectrographic analyses, respectively of p,p'DDT, p,p'DDT conditioned as a suspension in cardboard cartons, and a cardboard carton.

	p,p'DDT		Cardboard carton		Conditioned p,p'DDT	
	per cent.	mg.	per cent.	mg.	per cent.	mg.*
Sample weight	9.16 gm.		29.9 gm.		27.82 gm.	
Per cent. ash	0.01		3.1		0.68	
Ash weight	0.90 mg.		926.9 mg.		189.18 mg.	
Elements in ash						
Al	0.5	0.0045	15 to 25	139 to 232	3.8	0.058
Ca	5 to 10	0.045 to 0.09	1 to 3	9.3 to 27.8	47.3	0.727
Cu			0.1	0.93	1 to 5	0.029 to 0.145
Fe	5 to 10	0.045 to 0.09			1	0.029
Mg	0.5	0.0045	0.1	0.93	2	0.058
Mn					0.1	0.0029
Pb					0.1	0.0029
Si	10	0.09	8	74	5	0.145
Ti			matrix	constituent	0.1	0.0029
Ba			0.1	0.93	>0.01 & <0.1	>0.00029 & <0.0029
Cr			0.01	0.093	0.1	0.0029
Sr					0.01	0.00029
Na			0.3 to 0.5	2.8 to 4.6	25	0.727
Ag					1	0.029

* DDT was conditioned in 65 cartons, but weights are calculated as for one carton so they can be compared with carton ash data.

Larval tests.

As shown by fig. 2, the kill of Anopheline larvae exposed to DDT dispersions in cardboard cartons is consistently less than the kill obtained with dispersions in glass dishes. The standard deviations of the mortalities in glass were lower than those for the mortalities in paper. The differences in the kills of the two series are significant, based on a comparison of the difference of the means with the standard error of the difference. For our results, the product of these quantities always exceeded a value of two, except at the dosage of 0.05 p.p.m. DDT, for which the product was only 1.5.

The curves fitted by sight to the plotted means appear to be essentially parallel. The LD50 and LD90 values for the larvae exposed to DDT in cardboard as taken from these curves are about two and one-half times those for larvae exposed to DDT in glass.

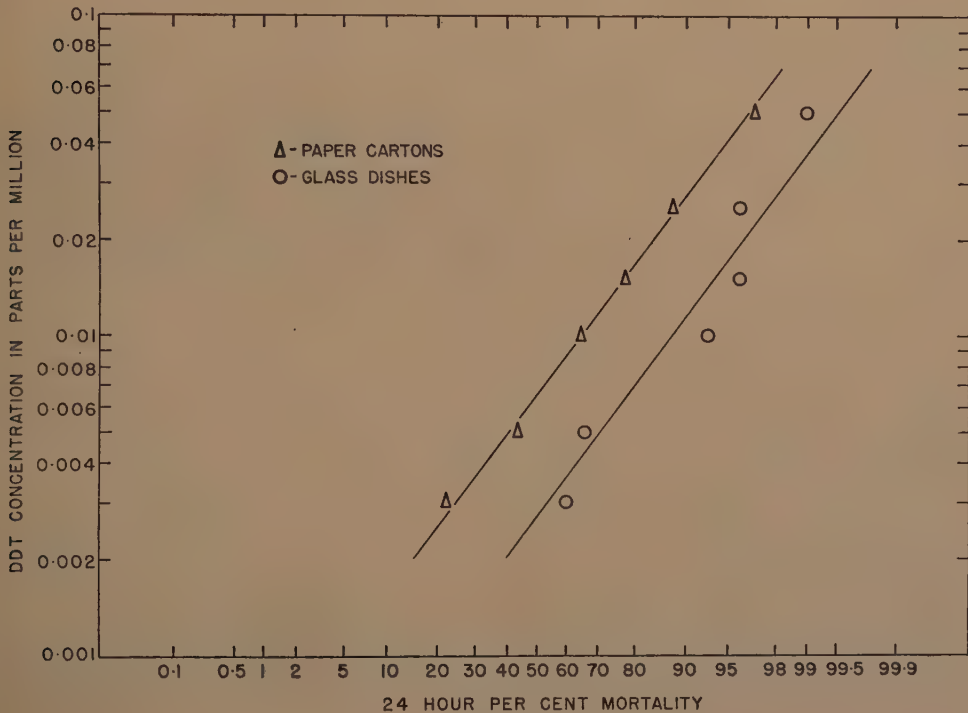


Fig. 2.—Comparative effectiveness against Anopheline larvae of aqueous suspensions of DDT in cardboard cartons and glass dishes (25 larvae per replicate).

Discussion and Conclusions.

It is acknowledged that the stability of a sol usually increases with increased zeta potential and that the zeta charge is dependent on the ionic environment. Our findings of a high zeta potential for a DDT suspension in glass dishes and a low zeta for suspensions in paper containers indicate extremes in stability conditions. A faster DDT flocculation rate in paper than in glass recorded by Krusé and his co-workers is supported by our mobility data. Even a coating of paraffin wax did not completely seal off the paper, since the zeta potential of a sol conditioned in the waxed carton was -6 mv. No doubt the wax coating was partially effective in sealing the ions in the cardboard since there was a 6 mv. increase in the zeta potential of the sol.

The electrophoretic data of the suspensions exposed to the four electrolytes clearly show the effects of ion species and concentration. The zeta behaved in a predictable pattern and showed that the charge on the DDT particles was governed by the ionic environment. Much lower concentrations of tri- and tetravalent ions than of mono- and divalent ions are needed to depress the zeta potential of a DDT sol to the isoelectric point. Though at certain concentrations of AlCl_3 and ThCl_4 considerable zeta potentials were recorded, the occurrence of similarly favourable conditions with contamination is quite unlikely. Contamination of a DDT suspension by ions would no doubt always create an unstable condition.

The spectrographic analyses pointed out two sources of contaminating ions, and indicated that there could be others. The cardboard carton was readily identified as being the major source of ions, while the DDT itself contributed a much smaller fraction. The finding of four ions, foreign to both of these sources, indicates that probably the distilled water, the DDT solvent or inadvertent contamination was their origin. Of course, the amounts of ions furnished by the cardboard are undoubtedly quite enough to depress the zeta potential to zero. The effect of the other ions could be a factor when glass or other relatively inert containers are used in larval testing. The spectrographic data show that for a sol conditioned in paper, ions must be the cause of the depressed zeta potential, which in turn allows flocculation to deplete the suspension of DDT.

The larval tests bore out this assumption. When the container for a test was glass, the larval kill was higher than when the container was paper. These differences in kill are attributed to the different amounts of DDT available to the mosquito larvae in each type of container. As predicted from zeta potential behaviour, the kill followed suspension stability.

The effect of ions originating other than in the DDT or the container is believed to have been a factor in these larval dosage response tests. The means of the larval mortalities in cardboard better fitted a straight line function than did the mortality means from glass. This is thought to have been due to the more constant DDT dosage in the cardboard. Since in the paper cartons the DDT sol was always at the isoelectric point, flocculation proceeded and the suspensions were uniformly degraded. Only the accuracy in application of the ethanolic DDT should influence larval kill. By contrast, the zeta potential of the DDT sol in glass, though substantial, was readily subject to the influences of any ions in the suspension. It is believed that inadvertent contamination by ions caused a higher rate of flocculation in certain tests and consequently altered kills. New and old glass dishes were used for these tests. A new glass surface is known to be a better source of ions than an old surface. It could have been that a chance grouping of old dishes for some tests and new dishes for others caused the scatter of the means.

Summary.

A DDT sol, prepared in glass dishes in the manner described, has a reproducible zeta potential of -25 mv. Electrophoretic measurements showed that DDT conditioned in cardboard cartons has a zeta potential of zero.

The zeta potential of the suspension behaves in a predictable and measurable manner in the presence of mono-, di-, tri-, and tetravalent ions.

Spectrographic analyses showed that there are two identifiable sources of ions: (1) the DDT, and (2) the cardboard container. A third source of ions was indicated as being, singly or together, the distilled water and/or the DDT solvent.

Spectrographic data showed that ions were associated with the conditioned DDT.

In glass containers, a poor source of ions, kill of larvae of *Anopheles quadrimaculatus* Say was higher than in paper containers, a good source of ions. These

data are correlated with the zeta potential and flocculation behaviour of DDT suspensions.

Acknowledgements.

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References.

- ABBOTT, W. S. (1925). A method of computing the effectiveness of an insecticide.—*J. econ. Ent.*, **18**, pp. 265-267.
- CROWELL, R. L. (1940). Insectary rearing of *Anopheles quadrimaculatus* (a preliminary report).—*Amer. J. Hyg.*, **32**, Sect. C pp. 12-20.
- CUTKOMP, L. K. (1947). Thermal decomposition of DDT dispersed in water.—*J. econ. Ent.*, **40**, pp. 444-445. 37 8 5.
- KRUSÉ, C. W., LUDVIK, G. F. & HAWKINS, W. B. (1952). Factors affecting evaluation of insecticides against *Anopheles* larvae.—*J. econ. Ent.*, **45**, pp. 598-601. 41 3 3.
- PRICE, C. W. & LEWIS, W. C. M. (1933). The electrophoretic behavior of lecithin and certain fats.—*Trans. Faraday Soc.*, **29**, pp. 775-787.
- SLAVIN, M. (1938). Quantitative analysis based on spectral energy.—*Industr. Engng Chem. (Anal.)*, **10**, pp. 407-411.
- UPHOLT, W. M. (1947). The inactivation of DDT used in Anopheline mosquito larvicides.—*Publ. Hlth Rep.*, **62**, pp. 302-309. 32 13
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NOTES ON THE BIOLOGY OF SOME PREDACIOUS MITES ON FRUIT TREES IN SOUTH-EASTERN ENGLAND.

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E.M.N.

The natural enemies of phytophagous mites on fruit trees have been the subject of investigation for many years, during which time a wide range of species of predacious insects has been studied throughout the fruit-growing regions of the world. In addition, various predacious mites have been recorded, amongst which are species of the families ANYSTIDAE, CHEYLETIDAE and BDELLIDAE, of relatively little importance in the control of phytophagous species, and members of the family LAELAPTIDAE, noted many years ago, which have for some time been considered to be of economic importance in North America, and more recently so in Europe. The taxonomy of these mites, and the species involved in different parts of the world, was obscure until Nesbitt (1951) published a revision of the subfamily PHYTOSEIINAE (family LAELAPTIDAE) to which they belonged. This monograph is based on material collected by the Dutch acarologist Oudemans, and includes many of his original drawings; it follows Garman (1948) in the terminology of the chaetotaxy, and replaces the genus *Iphidulus* put forward by Garman by that of *Typhlodromus*. More recently, papers on the PHYTOSEIINAE of the United States and Australia have been published by Cunliffe & Baker (1953) and Womersley (1954), respectively.

Historical.

Before the publication of Nesbitt's monograph, the species feeding on phytophagous mites had been referred to variously as *Seius pomi* Parr., *Seiulus pomi* (Parr.) or *Seius* sp. Parrott, Hodgkiss & Schoene (1906) in the United States described *Seius pomi* Parr. which they had found feeding on the Apple and Pear Blister Mite, *Eriophyes pyri* (Pgst.). Later, Ewing (1914) found the same species feeding on *Tetranychus telarius* (L.) and *T. mytilaspidis* (Ril.). Newcomer & Yothers (1929) confirmed this habit in the State of Washington in the Pacific Northwest where they found it feeding on *T. telarius* and *Metatetranychus ulmi* (Koch) (to which the author refers as the European Red Mite, *Paratetranychus pilosus* (C. & F.)). Gilliatt (1935) considered *Seiulus pomi* to be the most important of all predators attacking *M. ulmi* (here also referred to as *P. pilosus*) in Nova Scotian orchards, and his work has been followed up by Lord (1949-50) who has studied the effect of various spray materials on the relationship between predacious and phytophagous mites on apple trees. Recently, Herbert (1953) has listed the species of phytoseine mites that occur in Nova Scotia. Among other workers in North America who have considered these mites to be of some significance in the control of red spider mites are Putman (1942) in Canada, Cutright (1944) in Ohio, and Clancy & Pollard (1952) in Virginia.

In Europe, Geijskes (1939) included *Seius* sp. as a probable predator of *M. ulmi* and Kuenen (1947) compared the effect on *M. ulmi* of a predator of this type with that of a ladybird, *Stethorus punctillum* Weise. Kuenen mentioned two species, one of which he called *Typhlodromus similis* (Koch). MacGill (1939) described *T. thripsi* MacGill feeding on thrips in greenhouses and Evans (1952) pointed out that this species was *T. cucumeris* Oudm.

In a survey of the predators of *M. ulmi* in England, Collyer (1953) suggested that further study might show certain species of predacious mites to be more

important than previously supposed, and the PHYTOSEIINAE might be placed among the more important groups now known. Work has since been carried out comparing the effects of various fungicides on the relative levels of predacious mites and *M. ulmi* in the field (Collyer & Kirby, 1955).

Species of Phytoseiine Mites Found.

Collections of phytoseiine mites from orchards, mainly in Essex, with some in Kent, showed that a number of species occurred, particularly on trees that were neglected, or only occasionally sprayed. It was important to know how quickly these mites could infest sprayed trees and the sources whence they come. Collections of mites were therefore made from orchard weeds and hedgerow plants, and it became clear that their distribution was not directly related to the occurrence of phytophagous mites. Subsequently a fairly wide range of plants common in south-eastern England has been examined. The plants listed here have been determined by collections only, and not from breeding experiments, and no attempt has been made to study the feeding habits of the mites on the different plants. The following species have been found: *Typhlodromus tiliae* Oudm., *T. tiliarum* Oudm., *T. (Neoseiulus) rhenanus* (Oudm.), *T. finlandicus* (Oudm.), *T. cucumeris* Oudm., *T. masseei* Nesbitt, *T. umbraticus* Chant, *T. vitis* Oudm., *T. (Neoseiulus) soleiger* (Ribaga), *Phytoseius macropilis* (Banks) and two *Amblyseius* spp.

Brief Description of Species.

The nine species of *Typhlodromus* resemble each other closely, and can only be identified by careful examination. Certain measurements which are of value in separating species are given in Table I; all have been made from slide material but are of the chitinous parts which do not become distorted.

A key to the species, and details of all except *T. umbraticus* are given by Nesbitt (1951). Chant (1956) described *T. umbraticus*. Only macroscopic and important specific characters of the female mites are described here.

T. tiliae.—Body narrow and rectangular, relatively pale in colour; 4 pairs preanal setae on the ventrianal plate; 9 lateral setae on dorsal shield, conspicuous pore on dorsum in front of L9.

T. tiliarum.—Similar to *tiliae*, but body longer; ventrianal plate also long and narrow in the female; 11 lateral setae.

T. rhenanus.—Very similar to *tiliae*, often somewhat brown in colour and dorsum reticulated; 10 lateral setae.

T. finlandicus.—White and shining, body smooth and non-chitinous; broader, ovate in shape; ventrianal plate bears three pairs preanal setae and a pore.

T. cucumeris.—Brownish in colour, ventrianal plate of female almost as broad as long.

T. masseei.—Very large species, usually brown in colour; similar in appearance to *Amblyseius* species.

T. umbraticus.—Slightly larger than *tiliae*; 3 pairs of preanal setae on ventrianal plate.

T. vitis.—Small, pale in colour; ventrianal plate narrow, with 2 pairs preanal setae.

T. soleiger.—Brown in colour, dorsum reticulated; ventrianal plate characteristically long with a central constriction; 2 pairs preanal setae. The specimens collected which conform to this species fall into two groups, differing in size. The larger group (see Table I) are conspicuously larger than the other *Typhlodromus* species considered here with the exception of *T. masseei*; whereas the smaller (in brackets) is only slightly larger than average.

P. macropilis.—This species is easily distinguished from members of the genus

Typhlodromus by means of the large, serrated setae, which give the mite a rough appearance even to the naked eye. It is relatively slow moving, with long legs, and leg IV is considerably longer than the other legs.

Amblyseius spp.—The status of this genus is uncertain at the present, and it is not possible to give correct names to the two species that have been found in this investigation. They are larger than the *Typhlodromus* spp., both are 0.35×0.22 mm., and have very long legs. In general appearance they are large, brown and shining, and the body appears almost globular; they have always been found living with species of *Typhlodromus*, from which they are readily distinguishable by their size and greater activity.

TABLE I.

Measurements in millimetres of phytoseiine mites.

		Dorsal shield		Length of fore-leg	Ventrional plate	
		Length	Width		Length	Width
<i>Typhlodromus</i>	<i>tiliae</i> ♀	0.31	0.17	0.27	0.10	0.08
	♂	0.24	0.14	0.22	0.09	0.14
"	<i>tiliarum</i> ♀	0.33	0.17	0.24	0.10	0.07
	♂	0.25	0.14	0.22	0.10	0.13
"	<i>rhenanus</i> ♀	0.30	0.18	0.27	0.10	0.08
"	<i>finlandicus</i> ♀	0.33	0.22	0.31	0.10	0.07
	♂	0.25	0.16	0.27	0.09	0.13
"	<i>cucumeris</i> ♀	0.34	0.21	0.31	0.11	0.10
"	<i>masseei</i> ♀	0.48	0.30	0.39	0.15	0.13
"	<i>umbraticus</i> ♀	0.33	0.19	0.32	0.10	0.08
	♂	0.26	0.17	0.27	0.11	0.14
"	<i>vitis</i> ♀	0.28	0.18	0.23	0.09	0.06
	♂	0.28	0.17	0.23	0.12	0.15
"	<i>soleiger</i> ♀	0.39 (0.34)	0.23 (0.20)	0.31 (0.23)	0.13 (0.11)	0.07 (0.06)
	♂	0.28 (0.23)	0.16 (0.13)	0.27 (0.19)	0.11 (0.09)	0.12 (0.12)
<i>Phytoseius</i>	<i>macropilis</i> ♀	0.31	0.18	0.29	0.09	0.05
	♂	0.24	0.14	0.23	0.10	0.13

Plants on which Predacious Mites have been found.

T. tiliae.—This is the most abundant and widespread species in England, and according to Nesbitt is the predominant species in North America and continental Europe. It is the only species that becomes abundant on sprayed apple in England. It occurs on apple, plum, pear, hop, raspberry; on such trees as ash

(*Fraxinus excelsior*), birch (*Betula pubescens*), beech (*Fagus sylvatica*), elm (*Ulmus* sp.), hazel (*Corylus avellana*), maple (*Acer campestre*), hornbeam (*Carpinus betulus*), oak (*Quercus robur*), willow (*Salix* spp.); on the hedgerow bushes, bramble (*Rubus fruticosus*), dogwood (*Cornus sanguinea*), elder (*Sambucus nigra*), hawthorn (*Crataegus monogyna*), sloe (*Prunus spinosa*); and on herbaceous plants, agrimony (*Agrimonia eupatoria*), burdock (*Arctium lappa*), buttercup (*Ranunculus* spp.), coltsfoot (*Tussilago farfara*), hedge woundwort (*Stachys sylvatica*), hogweed (*Heracleum sphondylium*), *Potentilla reptans*, *Mentha rotundifolia*, nettle (*Urtica dioica*) and deadnettle (*Lamium purpureum*).

T. tiliarum.—This species is relatively uncommon; it has been found on a few plants only, and never abundantly. Nesbitt records it on apple, pear, and *Tilia* in Canada. It has been found in England on apple and elm, and occasionally on plum, nettle and agrimony.

T. rhenanus.—This species is recorded by Nesbitt as being abundant in Canada on cultivated fruit, and by Cunliffe & Baker (1953) on all types of vegetation in the United States. In south-eastern England it is one of the less common species, having been found on apple, bramble and hogweed, and less frequently on dogwood, hazel, agrimony, burdock and ash.

T. finlandicus.—This species is widespread and abundant, second only to *T. tiliae* in frequency. Nesbitt, and Cunliffe & Baker record it as being common throughout North America and also in South America and continental Europe. In England it occurs on apple, plum, damson, cherry, raspberry, gooseberry, peach and walnut, on many trees including ash, birch, oak, elm, sweet chestnut (*Castanea sativa*), alder (*Alnus glutinosa*), hornbeam and lime (*Tilia europaea*), on hedgerow bushes such as bramble, dogwood, elder, sloe, hawthorn and hazel, and less frequently on herbs such as burdock, nettle, rose-bay willow herb (*Chamaenerion angustifolium*) and buttercup.

T. cucumeris.—Nesbitt regards this species as uncommon in North America. In England it is also comparatively rare, a few specimens have been found on myrobalan, bramble and strawberry.

T. masseei.—Nesbitt described this species from apple twigs and leaves in Nova Scotia, and also had material collected at East Malling from unsprayed apple trees. In addition he found it on beans and *Tilia* in Canada. It is not common on fruit trees in England, but has been found occasionally on apple bark, and on the bark of oak and lime.

T. umbraticus.—This species is common in England, but somewhat restricted in the range of plants on which it has been found. It occurs on apple, where these are unsprayed, and bramble, and occasionally on maple. It has also been found on the following herbaceous plants:—hedge woundwort, nettle, hogweed, burdock, buttercup, agrimony, coltsfoot, *Potentilla reptans*, *Mentha aquatica* and *Mentha rotundifolia*.

T. vitis.—This species, described by Oudemans from grape vine (*Vitis vinifera*) in France, has according to Nesbitt not been collected again. It has been found in this investigation, although not frequently, on hazel and nettle.

T. soleiger.—This species was described by Ribaga from *Citrus* leaves, and Nesbitt has found it once on apple in Canada. In England it has been found relatively infrequently on a few species of plants, very occasionally abundantly. The larger form has been found on unsprayed plum and apple, the smaller form on hawthorn, bramble and oak.

P. macropilis.—Described originally by Oudemans from *Salix* in Finland, Nesbitt records it as abundant in North America and northern Europe. Herbert (1953) found it abundant in some Nova Scotian orchards. In England it is plentiful on unsprayed apple and plum, and also on bramble, maple, hornbeam, hazel, willow, elm and occasionally ash, sloe, sweet chestnut, coltsfoot, burdock, hogweed and nettle.

Amblyscius spp.—These species have been found on unsprayed apple, bramble, nettle, burdock and *Potentilla reptans*.

It might appear from a superficial study of these plant records that all species occur on a wide variety of plants, only some more commonly than others. There are, however, certain consistent differences. *T. tiliae* appears to be cosmopolitan, it has been found on a very high proportion of the types of plant examined, it is occasionally the only species present, but more often mixed with one or more other species. *T. finlandicus*, although common, generally occurs on trees, only rarely on herbaceous plants. *T. umbraticus* on the other hand favours herbs and is but rarely found on trees. Taking one type of plant, there are differences which may be related to leaf texture, e.g., within an apple orchard it has been found that *P. macropilis* is more abundant on varieties with a hairy undersurface to the leaves, whereas *Typhlodromus* spp. are dominant where the leaves are less hairy. A similar difference may also be seen where different plants are considered. *T. finlandicus* is most usually found on trees with smooth leaves and few hairs, e.g., oak, sweet chestnut, hawthorn, elder, where it is often the only species present. *P. macropilis* however, is found either on leaves with a completely hairy undersurface, e.g., some apple varieties, coltsfoot, salix, or where there is excessive hairiness along the midrib and veins, e.g., maple, hazel. *T. umbraticus* is common on hedge woundwort, nettle, deadnettle, *Mentha* spp., all of which have leaves of a similar texture and with a pungent odour, and it is almost without exception the only species ever found on hedge woundwort.

Life-history.

Field studies of these mites are difficult, as populations generally consist of more than one species. To supplement outdoor observations, mites were kept indoors in unheated laboratory conditions for the details of life-history and feeding habits. They have been reared successfully on leaves, either of apple or *Prunus spinosa*, floating ventral surface upwards on cotton-wool in open petri dishes of water, and not exposed to bright sunlight.

Eggs.

The phytoseiine eggs are ovoid, colourless and translucent. The average sizes for three species are: *T. tiliae* 0.18 × 0.11 mm.; *T. soleiger* (large form) 0.21 × 0.14 mm.; *P. macropilis* 0.17 × 0.13 mm. They are laid singly on the ventral surface of the leaves, where they may be placed on the leaf itself, at the tip of a leaf hair, or suspended in the webbing of a phytophagous mite species such as *Tetranychus telarius* (= *urticae* Koch). *Typhlodromus tiliae* and *Phytoseius macropilis* generally oviposit on the leaf surface, often near to the midrib or leaf veins, whereas *T. finlandicus* and *T. umbraticus* more often place them at the tip of leaf hairs. *T. soleiger*, the larger form, has been noted laying its eggs in close groups beneath the midrib of plum leaves.

Eggs are laid by overwintering females from late April onwards, although in the field the first peak of egg-laying does not usually occur until May or even early June. In the laboratory, the incubation period of the eggs varies considerably with temperature. For *T. tiliae* the average incubation period over the years 1951–54 was 8, 6, 4½, 4, 5, 7½ days, respectively, for the months April–September; the overall range was from a minimum of two days in July and August to ten in April. Less frequent observations were made on some of the other species: *T. finlandicus*, May, 7 days (range 6–8), August, 3½ days (range 2–5); *T. umbraticus*, July–August, 4½ days (range 2–7).

Immature stages.

The larva is colourless and almost transparent; it does not appear to feed, and moults within one or two days into the first of the two nymphal stages. The

duration of the immature stages, from hatching to the appearance of the adults, is from 9 to 14 days in *T. tiliae*, 13–18 days in *P. macropilis* and somewhat longer (average 19 days) in *T. umbraticus*.

Adults.

In the laboratory, the usual length of life of the adult females in the summer is from 20 to 30 days; they may however live much longer than this, and the longevity records are 52 days for *T. tiliae*, 71 for *T. umbraticus* and 77 for *P. macropilis*. The males live a somewhat shorter time. The preoviposition period seems to be variable, and is sometimes as long as 14 days. In *T. tiliae*, eggs are laid at the average rate of one per day; this may be as high as two per day for short periods, but as the females get older egg-laying drops off. *T. finlandicus* lays eggs at similar intervals. The greatest number of eggs laid by one female in the laboratory is 32 for *T. tiliae*.

Number of generations.

Mites of the species *T. tiliae*, *T. finlandicus*, *T. umbraticus* and *P. macropilis* bred in the laboratory have in most cases passed through three complete generations in the summer. In 1953, however, from females of *T. tiliae* collected in the third week of May, four generations were completed before the development of overwintering females in mid-September.

Field Populations.

Gross populations have been recorded to study the number of generations that occur outdoors and in most cases therefore more than one species has been recorded together. Leaf samples were taken at frequent intervals—usually every three days—and the numbers of all stages recorded directly by examination under a binocular microscope.

Populations on a small group of cultivated plum trees are shown in fig. 1;

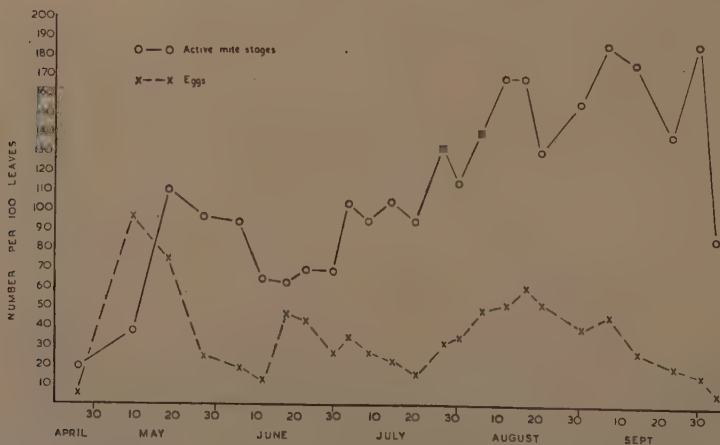


Fig. 1.—Phytoseiine populations in unsprayed plum orchard, Essex, 1952.

these trees had been unsprayed for several years, *M. ulmi* was at a very low level, and the insect predators relatively scarce. The phytoseiine mites were mainly *T. finlandicus* with some *T. tiliae* and *T. soleiger*, and they remained at a relatively high density throughout the year. As a comparison, fig. 2 shows densities on a group of the same trees that were sprayed in the preceding winter with a tar

oil wash, showing the rapid increase of the mites that followed some months after their almost complete destruction. Populations of phytoseiine mites in a completely neglected apple orchard are shown in fig. 3; these were *T. tiliae*, *T. finlandicus* and *P. macropilis*. The level of actual numbers of mites per leaf is lower here than on the plum trees, as large numbers of predacious insects,

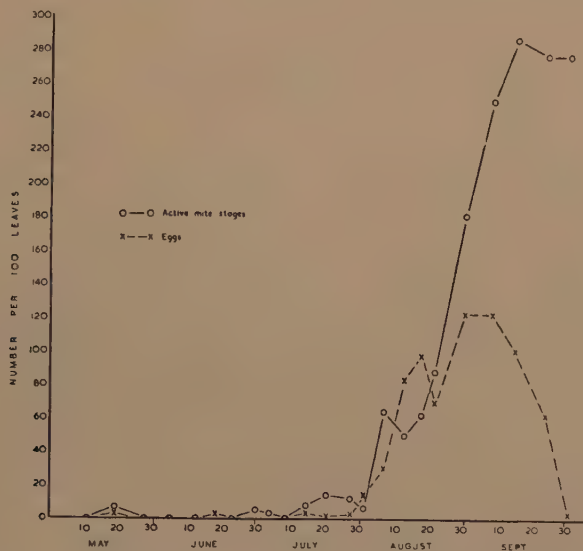


Fig. 2.—Phytoseiine populations in plum orchard following tar oil winter wash, 1952.

particularly Mirids and Anthocorids, are always active throughout the summer. Where field populations have been recorded, three distinct peaks of eggs have generally been apparent as in figs. 1 and 3, indicating the probable occurrence of three generations and thereby supporting the laboratory observations. There is

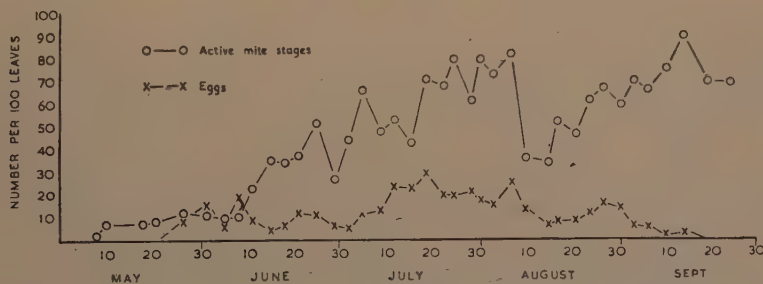


Fig. 3.—Phytoseiine populations in unsprayed apple orchard, Essex, 1951.

considerable overlap between generations of adults, which may live many weeks; the eggs give a clearer separation of generations, and the egg peaks represent a large number of eggs as the incubation period may be as short as two days.

Feeding Habits.

Many authors have recorded phytoseiine mites feeding on species of the family TETRANYCHIDAE. Gilliatt (1935) in Canada states that *Seiulus pomi* consumes

on an average two European Red Mites per day. Dean (1953) finds *T. finlandicus* on *Citrus* in Texas associated with *Phyllocoptruta oleivora* (Ashm.) and *Eutetranychus banksi* (McG.) (referred to as *E. clarki* (McG.)); Fleschner & Ricker (1954) report the same species on *Citrus* and avocado in California feeding on *Citrus* Red Mite (*Metatetranychus citri* (McG.)), *Citrus* Bud Mite (*Aceria sheldoni* (Ewing)) and Avocado Brown Mite (*Oligonychus punicae* (Hirst), referred to here as *Paratetranychus coiti* McG.).

In England, phytoseine species commonly found on fruit trees feed on the tetranychid mite species, *M. ulmi*, *T. telarius*, *Eutetranychus carpini* (Oudm.) and *Bryobia praetiosa* Koch. All active stages of *M. ulmi* are attacked, and also the summer eggs, although there is some difficulty in penetrating the eggs; predacious mites are often found on the wood where winter eggs of *M. ulmi* occur, but have not been observed actually feeding on them. All stages of both *T. telarius* and *E. carpini* are readily eaten, in particular the eggs which are easily penetrated; both of these species live in colonies surrounded by webbing, within which the predacious mites live with their prey. Larvae of *B. praetiosa* are often eaten, especially in April when other mites are not available, but neither eggs nor older mites are attacked. In addition, mites of the family ERIOPHYIDAE serve as a source of food for phytoseines, but they have not been considered in this investigation. All stages of the predacious mites except the larvae feed on these phytophagous mites, and may also occasionally feed on members of their own species, although cannibalism is probably not important in the field.

Phytoseine mites can survive at a very low density of prey and at times it would appear that none is available. It is obvious that they also feed on plant tissue and, in laboratory tests, individual mites provided with only plant food survived for a considerable length of time, but did not lay eggs and lived for a shorter time than those with phytophagous mites and plant material as food.

In the laboratory, an estimate has been made of numbers of adults of *M. ulmi* consumed daily when plenty are available. Most of the counts were made in July and August, when activity and food consumption are probably at their highest. The average numbers consumed per day were: by adults of *T. tiliae*, 3 mites per day, by nymphs, 2; by adults of *P. macropilis*, 2.5, by nymphs, 2. Egg-laying female mites consume as many as 5 mites per day.

Summary.

A number of predacious mites of the PHYTOSEIINAE (family LAELAPTIDAE), found in south-eastern England, mostly in association with fruit trees, are listed. Certain measurements and other characters that are of value in separating species are given. The species found were: *Typhlodromus tiliae* Oudm., *T. cucumeris* Oudm., *T. tiliarum* Oudm., *T. rhenanus* (Oudm.), *T. finlandicus* (Oudm.), *T. umbraticus* Chant, *T. masseei* Nesbitt, *T. vitis* Oudm., *T. soleiger* (Ribaga), *Phytoseius macropilis* (Banks) and two *Amblyseius* spp. Of these, *T. tiliae*, *T. finlandicus* and *P. macropilis* are normally abundant on apple trees, but only *T. tiliae* remains abundant on commercially-grown apple trees. For each species a list of plants on which it has been found is given.

Details of the life-history of laboratory-reared mites are given and these, together with counts of field populations, show that three generations a year is normal.

Predacious phytoseine mites feed on several species of TETRANYCHIDAE, including *Metatetranychus ulmi* (Koch) and *Tetranychus telarius* (L.); when *M. ulmi* is supplied in adequate numbers, adults of *T. tiliae* consume 3 mites per day, the nymphs 2 mites per day, on an average. It is thought that they also feed on plant tissue, since individuals survived in the laboratory for a considerable length of time in the absence of phytophagous mites, though eggs were not laid.

References.

- CHANT, D. A. (1956). Some mites of the subfamily Phytoseiinae (Acarina: Laelaptidae) from southeastern England, with descriptions of new species.—*Canad. Ent.*, **88**, pp. 26–37.
- CLANCY, D. W. & POLLARD, H. N. (1952). The effect of DDT on mite and predator populations in apple orchards.—*J. econ. Ent.*, **45**, pp. 108–114.
- COLLYER, E. (1953). Biology of some predatory insects and mites associated with the Fruit Tree Red Spider Mite (*Metatetranychus ulmi* (Koch)) in south-eastern England. IV. The predator-mite relationship.—*J. hort. Sci.*, **28**, pp. 246–259.
- COLLYER, E. & KIRBY, A. H. M. (1955). Some factors affecting the balance of phytophagous and predacious mites on apple in south-east England.—*J. hort. Sci.*, **30**, pp. 97–108.
- CUNLIFFE, F. & BAKER, E. W. (1953). A guide to the predatory Phytoseiid mites of the United States.—*Publ. Pinellas biol. Lab.*, no. 1, 28 pp.
- CUTRIGHT, C. R. (1944). Populations of the European Red Mite as affected by spray schedules.—*J. econ. Ent.*, **37**, pp. 499–502.
- DEAN, H. A. (1953). Spider mites of *Citrus* and Texas Citrus Mite control in the Lower Rio Grande Valley of Texas.—*J. econ. Ent.*, **45**, pp. 1051–1056.
- EVANS, G. O. (1952). A new Typhlodromid mite predacious on *Tetranychus bimaculatus* Harvey in Indonesia.—*Ann. Mag. nat. Hist.*, (12) **5**, pp. 413–416.
- EWING, H. E. (1914). The Common Red Spider or Spider Mite.—*Bull. Ore. agric. Exp. Sta.*, no. 121, 95 pp.
- FLESCHER, C. A. & RICKER, D. W. (1954). Typhlodromid mites on *Citrus* and avocado trees in southern California.—*J. econ. Ent.*, **47**, pp. 356–357.
- GARMAN, P. (1948). Mite species from apple trees in Connecticut.—*Bull. Conn. agric. Exp. Sta.*, no. 520, 27 pp.
- GEIJSKES, D. C. (1939). Beiträge zur Kenntnis der europäischen Spinnmilben (Acari, Tetranychidae), mit besonderer Berücksichtigung der niederländischen Arten.—*Meded. LandbHoogesch. Wageningen*, **42**, no. 4, 68 pp.
- GILLIATT, F. C. (1935). Some predators of the European Red Mite, *Paratetranychus pilosus* C. & F., in Nova Scotia.—*Canad. J. Res.*, (D) **13**, pp. 19–38.
- HERBERT, H. J. [1953]. Progress report on predacious mite investigations in Nova Scotia (Acarina: Phytoseiidae).—*Rep. ent. Soc. Ont.*, **83**, pp. 27–29.
- KUENEN, D. J. (1947). On the ecological significance of two predators of *Metatetranychus ulmi* C. L. Koch (Acari, Tetranychidae).—*Tijdschr. Ent.*, **88**, pp. 303–312.
- LORD, F. T. (1949–50). The influence of spray programs on the fauna of apple orchards in Nova Scotia. III. Mites and their predators.—*Canad. Ent.*, **81**, pp. 202–214, 217–230.
- MACGILL, E. I. (1939). A Gamasid mite (*Typhlodromus thripsi* n. sp.), a predator of *Thrips tabaci* Lind.—*Ann. appl. Biol.*, **26**, pp. 309–317.
- NESBITT, H. H. J. (1951). A taxonomic study of the Phytoseiinae (family Laelaptidae) predaceous upon Tetranychidae of economic importance.—*Zool. Verh.*, no. 12, 64 pp.
- NEWCOMER, E. J. & YOTHERS, M. A. (1929). Biology of the European Red Mite in the Pacific Northwest.—*Tech. Bull. U.S. Dep. Agric.*, no. 89, 69 pp.

- PARROTT, P. J., HODGKISS, H. E. & SCHOENE, W. J. (1906). The Apple and Pear Mites.—Bull. N.Y. agric. Exp. Sta., no. 283, pp. 281–318.
- PUTMAN, W. L. (1942). Notes on the predaceous thrips, *Haplothrips subtilissimus* Hal. and *Aeolothrips melaleucus* Hal.—Canad. Ent., **74**, pp. 37–43.
- WOMERSLEY, H. (1954). Species of the subfamily Phytoseiinae (Acarina: Laelaptidae) from Australia.—Aust. J. Zool., **2**, pp. 169–191.
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**SPODOPTERA MAURITIA (BOISDUVAL) AND *S. TRITURATA*
(WALKER), TWO DISTINCT SPECIES.**

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(PLATE VI.)

In working out a collection of Heterocera made by J. D. Bradley in the Solomon Islands, preparations were made of the genitalia of specimens of *Spodoptera mauritia* (Boisd.) and they were found to differ from those of African specimens, with which they were compared. Subsequent study of the material in the British Museum has shown that two species have been confused under the one name; *S. mauritia*, which occurs in Madagascar, Mauritius, the Comoro Islands and from India to the Pacific and which is known from continental Africa from only a single female taken at Lindi on the coast of Tanganyika, and the second species, *S. trituratora* (Wlk.), which occurs throughout continental Africa, south of the Sahara Desert. As both species are of economic importance, it has been decided to describe their differences in a separate paper rather than include them in the faunistic paper dealing with the Heterocera of Rennell Island.

S. mauritia has been recorded many times during the past forty years as a pest of young graminaceous crops in Mauritius and in the Indo-Australian and Pacific regions.

During the same period there have been two records of this species attacking Gramineae in Africa, but re-examination of the specimens concerned has shown that one record (Jack, 1942, Ann. Rep. Div. Ent. S. Rhod., 1941, p. 7) refers to *S. cilium* Gn. (1852) and the other (Dick, 1943, S. Afr. Sug. J., 27, p. 212) refers to *S. trituratora*.

The types of *S. mauritia* and *S. acronyctoides* Gn. are lost. The figure of the former species, accompanying the original description, leaves its identity in no doubt; the description of the latter is sufficient to ensure identification. The types of all the synonyms included in this paper are in the British Museum.

The colour names used are taken from Ridgway's "Color Standards and Color Nomenclature".

I should like here to express my thanks to Mr. W. H. T. Tams, who had already done the greater part of the work involved and has generously allowed me the free use of his notes.

***Spodoptera mauritia mauritia* (Boisduval) (Figs. 1, 4, 8, 11, 12).**

Hadena mauritia Boisduval, 1833, Faune ent. Madagascar, Lep., p. 92, pl. 13, fig. 9.

Agrotis aliena Walker, 1865, List Lep. Ins. B.M., 32, p. 694.

Male.—Palpus and head cinnamon buff irrorate with brownish vinaceous; thorax and crest on first abdominal segment brownish vinaceous irrorate with fuscous; abdomen pale pinkish buff with long, drab grey hairs dorsally and irrorate with cinnamon buff and brownish vinaceous ventrally. Forewing elongate and narrow. Proximal of the antemedial fascia, which is dentate and fuscous black edged proximally with white, the wing is a mixture of snuff brown and vinaceous brown, very lightly irrorate with fuscous and white. In some specimens there are traces of a dentate, fuscous, basal fascia. The medial area, posterior of vein

Cu2, is similarly coloured; between the subcostal vein and *Cu2* it is white with an orbicular spot ringed and centred with fuscous and a large fuscous black reniform, the latter joined to the vinaceous brown costa by an ill-defined medial shade. The band between the dentate, white subterminal and the postmedial fasciae is vinaceous brown from the costa to vein *M2* and then densely suffused with fuscous to just posterior of vein *Cu1*; the posterior third is white very lightly irrorate with vinaceous brown and the area distad of the subterminal fascia is similarly coloured, except between veins *M1* and *M3*, where there is a small but conspicuous patch of fuscous. The apex of the terminal area is almost pure white. There is a terminal row of fuscous, interneural spots. Underside glossy, pale pinkish buff; the anterior half is irrorate with brownish vinaceous and distally lightly suffused with fuscous; reniform and terminal spots fuscous. Hind wing almost hyaline, varying with the light from white to vinaceous; the margins and the veins are suffused with fuscous. Underside similar but with fuscous suffusion in the costal area only.

Female.—Differs from the male in the forewing, lacking the conspicuous white markings of the medial area and of the posterior third of the band between the postmedial and subterminal fasciae; those of the area distad of the subterminal fascia are reduced; instead all are irrorate with fuscous.

Male genitalia.—Uncus curved ventrad and tapered to a fine point. Valve with large corema bearing dense, deciduous hair tufts; ventral margin shallowly incised just before apex; the part of the valve apicad of the level of the ventral incision is as broad as long. A tapered process arises from mid-valve. Vesica with a single cornutus, three-fifths as long as the aedeagus; the apical fifth obtusely angled and covered with several small teeth.

Female genitalia.—Ostium bursae and ductus bursae sclerotized and of equal length. Posterior three-sevenths of bursa copulatrix cylindrical, ribbed and partially sclerotized posteriorly; anterior four-sevenths globular and ribbed with a single, longitudinal, scobinate signum.

Distribution: MAURITIUS; MADAGASCAR; COMORO IS.; TANGANYIKA (Lindi, 1 ♀).

***Spodoptera mauritia acronyctoides* Guenée (Figs. 2, 5).**

- Spodoptera acronyctoides* Guenée, 1852, Hist. nat. Ins., Spec. gén. Lép., 5, p. 154.
- Spodoptera nubes* Guenée, 1852, t. c., p. 155.
- Spodoptera filum* Guenée, 1852, l. c.
- Prodenia infecta* Walker, 1856, List Lep. Ins. B.M., 9, p. 196.
- Prodenia insignata* Walker, 1856, t. c., p. 197.
- Agrotis transducta* Walker, 1856, op. cit., 10, p. 344.
- Prodenia permunda* Walker, 1857, op. cit., 11, p. 723.
- Laphygma squalida* Walker, 1865, op. cit., 32, p. 652.
- Prodenia venustula* Walker, 1865, t. c., p. 654.
- Agrotis submarginalis* Walker, 1865, t. c., p. 699.
- Agrotis bisignata* Walker, 1865, t. c., p. 702.
- Hadena obliqua* Walker, 1865, op. cit., 33, p. 736.
- Spodoptera mauritia* ab. *effeminata* Warren, 1911, in Seitz, Gross-Schmett. Erde, 3, p. 207.

Differs from the nominate subspecies in the forewing. In the male the conspicuous white of the medial band is reduced to a small spot between the reniform and the orbicular; that of the terminal area is reduced to a small patch near the apex. In the female the white subterminal fascia is much more slender and the white terminal markings are replaced by fuscous irroration.

Distribution: RED SEA; INDIA; BURMA; SIAM; CHINA, Hainan, Shanghai; CEYLON; MALAY PENINSULA to AUSTRALIA; SOLOMON Is.; NEW HEBRIDES; FIJI; SAMOA; SOCIETY Is.; AUSTRAL Is.; MARQUESAS Is.; MARSHALL Is.; HAWAIIAN Is.

The treatment of *S. mauritia* at this stage does little more than separate the distinctive nominate subspecies from the populations of the Oriental, Indo-Australian and Pacific regions, which are grouped together under the oldest available name, *acronyctoides* Gn. Many of the specimens from Samoa and Fiji have rather darker hind wings and a short series received recently from Oahu in the Hawaiian Is. approaches closely the nominate subspecies. Until adequate material is available however, it would be unwise to attempt further subdivision.

***Spodoptera trituratora* (Walker) (Figs. 3, 6, 7, 9, 10).**

Caradrina trituratora Walker, 1856, List Lep. Ins. B.M., **10**, p. 295.

Laphygma gratiose Walker, 1865, *op. cit.*, **32**, p. 651.

Celaena bisignata Walker, 1865, *t. c.*, p. 679.

Spodoptera mauritia ab. *foeminalis* Strand, 1916, Arch. Naturgesch., (A) **81**, no. 11, p. 159.

Spodoptera mauritia Boisduval Janse *nec* Boisduval, 1937-39, Moths S. Africa, **3**, p. 158, fig. 48; 1940, pl. 10 figs. 5-7; pl. 28 fig. 2.

Spodoptera mauritia Boisduval Dick *nec* Boisduval, 1943, S. Afr. Sug. J., **27**, p. 212.

Differs from *mauritica* superficially in the forewing, which is less produced, more rounded apically and more uniformly grey; in the male all the conspicuous white markings, except for a slender, dentate, subterminal fascia, are wanting. In both sexes the band between the postmedial and the subterminal fasciae is narrower and the fuscous shading between veins *M*2 and *Cu*1 consequently reduced in size; the fuscous patch distad of the subterminal fascia, between veins *M*1 and *M*3, is wanting.

In the male genitalia the ventral margin of the valve is incised nearer the apex; the part of the valve apicad of the level of the incision is twice as broad as long. The vesica bears a dense patch of slender spines and a single cornutus with a smooth, tapered apex, the whole being one-half as long as the aedeagus.

The female genitalia differ in the length of the sclerotized ductus bursae, which is twice as long as the sclerotized ostium bursae.

Distribution: CONTINENTAL AFRICA, south of the Sahara Desert.

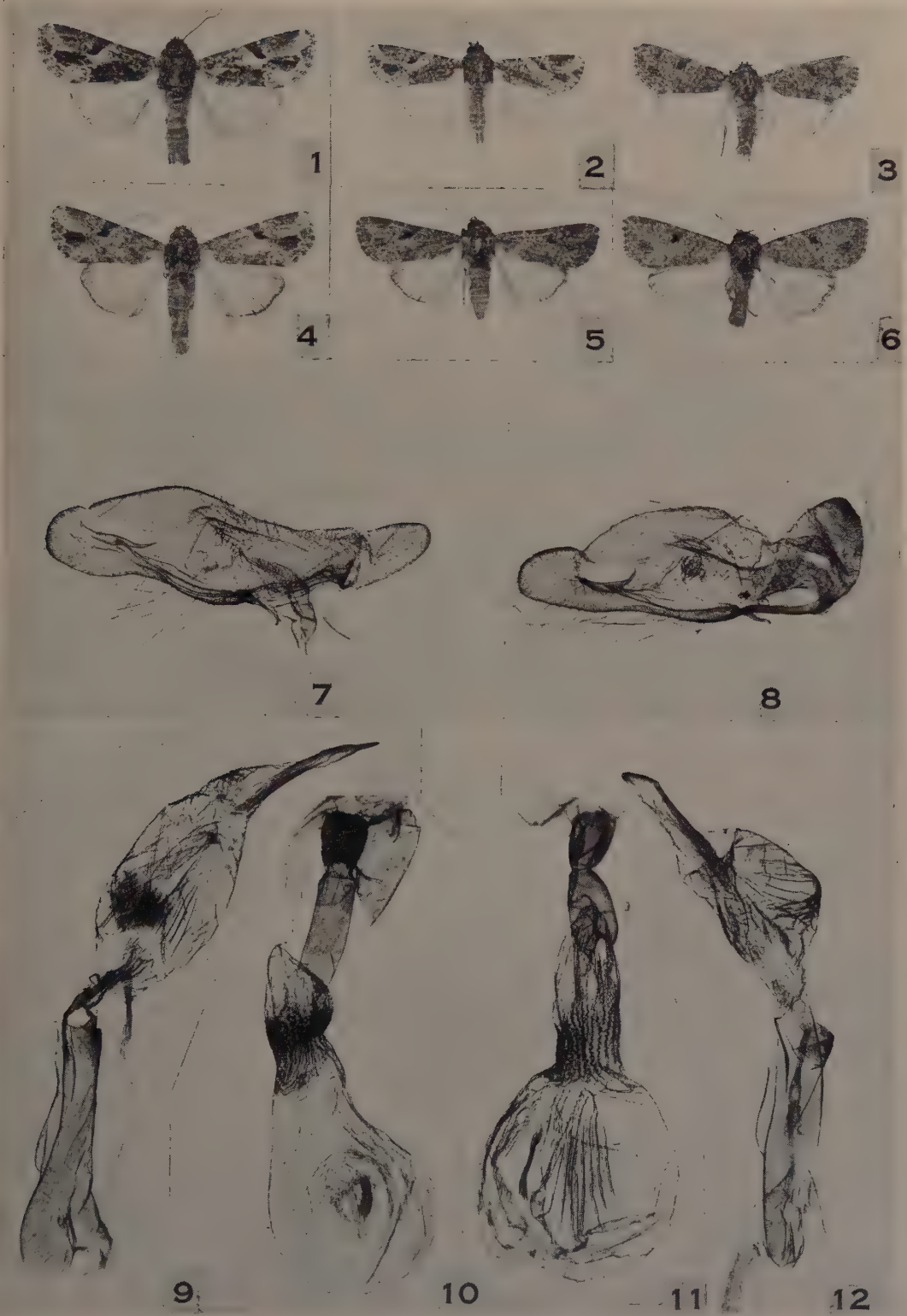


FIG. 1. *Spodoptera mauritia mauritia* (Boisd.), ♂. FIG. 2. *S. mauritia acronyctoides* Gn., ♂. FIG. 3. *S. trituratora* (Wlk.), ♂. FIG. 4. *S. m. mauritia*, ♀. FIG. 5. *S. m. acronyctoides*, ♀. FIG. 6. *S. trituratora*, ♀. FIG. 7. *S. trituratora*, left valve. FIG. 8. *S. mauritia*, left valve. FIG. 9. *S. trituratora*, aedeagus and vesica. FIG. 10. *S. trituratora*, ♀ genitalia. FIG. 11. *S. mauritia*, ♀ genitalia. FIG. 12. *S. mauritia*, aedeagus and vesica.

THE CONTROL OF *CREMATOGASTER* ANTS AS A MEANS OF
CONTROLLING THE MEALYBUGS TRANSMITTING
THE SWOLLEN-SHOOT VIRUS DISEASE OF
CACAO IN THE GOLD COAST.

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E.H.N.

(PLATE VII.)

The main mealybug vectors of the swollen-shoot virus disease of cacao in the Gold Coast are *Pseudococcus njalensis* Laing, *Planococcus citri* (Risso) and *Ferrisiana virgata* (Ckll.).

P. njalensis is the most important species of Pseudococcid in the Gold Coast, as it constitutes about 98.9 per cent. of the total population of the above mentioned three species.

Strickland (1951), in a mealybug field survey in the Gold Coast, found that out of 189,267 *P. njalensis*, 185,945 were directly associated with ants of coccidophilic habit, usually *Crematogaster*ine, and only 840 mealybugs were not attended by coccidophilic ants. The ratio is 1 to 225, as compared with 1 to 6 in *P. citri* and 1 to 2.3 in all other species. *P. njalensis* is, therefore, almost always associated with ants.

The ants attending the cacao mealybugs usually build their nests in the cavities and galleries that have already been excavated by wood-boring insects in dead branches of cacao trees. The tent constructed round the mealybugs consists mainly of vegetable and wood particles glued together with the secretion of a gland associated with the mouth-parts. In each tent there are one or more small round holes to permit the *Crematogaster* ants to enter, but not big enough to allow parasites or predators, bigger than the ants in size, to pass inside. (Plate VII, fig. 3.) Adult mealybugs cannot escape through these openings, and it is remarkable that the ants not only construct these tents but that they also maintain them. Tents which became empty of mealybugs by the action of a systemic insecticide or for other reasons are no more attended by ants and usually fall to pieces after a short time.

The conditions which induce the ants to build tents round the mealybugs are not fully understood, but it seems that rain is a major factor. In an experiment carried out at Tafo, to investigate the land migration of mealybugs from cut trees, two large cacao trees containing about 1,000 mealybug colonies were cut down and heaped in the middle of 75 small trees (about 6 to 9 ft. high) which were previously freed from mealybugs by destroying the tents and then spraying four times with nicotine sulphate. Fifteen of these trees were covered by small rain-proof roofs as shown in Plate VII, figs. 1 and 2. It is interesting to note that the above experiment started on the 13th November 1952, and there was no rain until the 27th, upon which date 0.09 inches were recorded. During this dry period, only three tented colonies were found on the 75 trees, but when they were examined on the 27th, a few hours after rain, there were 159 tented colonies on the uncovered trees. The examination, on the same date, of the 15 trees covered with rain-proof roofs, showed that there were 50 colonies, and none of them was covered by an ant-constructed tent. It seems, therefore, that rain is an important factor in the construction of tents.

The only apparent advantage of this association, so far as the ants are concerned, is to imbibe honeydew from the anal orifice of the mealybugs. As the plant sap seems to undergo chemical changes in the digestive system of mealybugs, whereby the dilute cane sugar is converted into a more concentrated invert sugar, the honeydew provides a more suitable form of nourishment than can be obtained by direct feeding on plant juices.

Attempts to break the Link between the Mealybugs and the Ants.

It was obvious that the mutual association between the mealybugs and ants could not continue if it was not advantageous to both of them. The question is, what happens to the mealybugs if they are not attended by ants.

In the following experiments, the method used for assessing the mealybug population was similar to that described in a previous paper (Hanna, Judenko & Heatherington, 1955), the number of mealybugs in a certain number of colonies being taken at random from each tree before and after treatment. The object of including control trees was to be sure that no sudden change in the population occurred during the course of the experiments, due to climatic or other factors.

Before starting these experiments, it was thought necessary to find out whether DDT, which was to be used in controlling the ants, had a direct effect on mealybugs. Three isolated pairs of trees were sprayed respectively with 0.2 per cent. DDT emulsion, with a similar emulsion after protecting the tents with Cellophane, and with water. A tanglefoot grease band was painted round the trunk one foot above the soil level to prevent ants climbing up the stem. Any ants present on those trees sprayed with DDT were killed but they persisted on those receiving water treatment. The results after two weeks are given in Table I.

TABLE I.

The effect of DDT on mealybugs.

Treatment	No. of mealybugs in 13 colonies		Size of population as a percentage of that before treatment
	Before treatment	No. of dead mealybugs after treatment	
1. Spraying with DDT	159	4	97.5
2. Covering the colonies before spraying with DDT	149	8	94.6
3. Spraying with water only	166	0	100

Nos. 1 and 2: Big drops of honeydew appearing in the colonies and also grey mould (*Penicillium* and *Aspergillus* species) which was obvious on the outside walls of the tents. Ants were absent.

No. 3: No honeydew or mould appearing. Ants were present.

The above experiment indicated that DDT had very little direct effect on mealybugs.

The following experiments were then carried out in an attempt to break the association between the ants and mealybugs. It will be noticed that trees were selected that were away from giant trees and climbers, and not in touch through the canopy with other trees which could be a source of *Crematogaster* ants.

Spraying the cacao trees twice with DDT after eliminating the sources of ants.

Six trees not in contact with each other or any other trees were sprayed each with 3.5 litres of 0.2 per cent. DDT emulsion, after cutting off all dead branches containing nests of ants, and painting, on the trunk, a band of grease one foot above soil level to prevent ants climbing up. The trees were also carefully examined to locate any nests in the crevices and under the bark and expose them to the action of DDT. Two weeks later, the trees were sprayed again. Four weeks after the first application of spray, the results were as shown in Table II.

TABLE II.

	No. of live mealybugs in 240 colonies—40 per tree		Size of population as a percentage of that before treatment
	Before treatment	4 wks. after treatment	
DDT	1852	22	1.2
Control (80 colonies)	643	665	—

Dead mealybugs were found inside the colonies, but it was impossible to count them owing to the growth of mould.

The result of the above experiment indicates that two DDT sprays, after eliminating all the sources of ants, reduced the population to a very low level. Unfortunately, locating the nests in the crevices and under the bark is very difficult, and it was thought advisable to try and simplify the method.

Spraying with insecticides without eliminating the sources of ants.

Spraying the trees with DDT only.—Four trees were sprayed once only with 0.2 per cent. DDT emulsion and one tree was left untreated. Unlike the previous experiment, the dead branches containing nests of ants were not cut off. After four weeks, mould appeared inside the treated colonies and was obvious on the outer walls of the tents. The result, four weeks after treatment, is shown in Table III and it can be seen that the reduction in the mealybug population was unsatisfactory. It seems likely that DDT was only effective in controlling the ants that came in contact with it, but ineffective against the immature stages which were protected in the nests; those that emerged after the DDT had lost its effectiveness were not affected.

TABLE III.

	No. of live mealybugs in 160 colonies—40 per tree		Size of population as a percentage of that before treatment
	Before treatment	4 wks. after treatment	
DDT	1282	215	16.8
Control (40 colonies)	400	385	—

The size of the population, compared with that before treatment, was followed up after six and eight weeks, and was found to be 39.4 and 92.3 per cent., respectively, an unsatisfactory result.

Spraying with DDT and parathion.—In the following experiment, four trees were sprayed with 3.5 litres per tree of a mixture of 0.2 per cent. DDT and 0.02 per cent. parathion active material; one tree was left as control. Counts of live mealybugs before treatment and four weeks later are recorded in Table IV.

TABLE IV.

	No. of live mealybugs in 160 colonies—40 per tree		Size of population as a percentage of that before treatment
	Before treatment	4 wks. after treatment	
DDT plus parathion	1224	142	11.6
Control (40 colonies)	271	296	—

After six and eight weeks, the size of population compared with that before treatment was 64.3 and 58.8 per cent., respectively, a reduction in population that was still unsatisfactory.

Cutting off the dead branches containing the nest of ants, followed by a partial treatment with DDT.

- (A) Painting the cut end of the dead branches with DDT (16.7% emulsion) or
- (B) Painting a ring of DDT (16.7% emulsion) on the trunk, one foot above soil level, to prevent ants climbing up the trees.

Eight trees were taken for each treatment and two were left untreated. Six weeks after the treatment, the result was as shown in Table V.

TABLE V.

Treatment	No. of live mealybugs in 80 colonies—10 per tree		Size of population as a percentage of that before treatment
	Before treatment	6 wks. after treatment	
(A)	1867	514	27.5
(B)	538	740	100
Control 100 colonies— 50 per tree	1375	1444	—

From the above experiments, it can be seen that it is extremely difficult to control a group of insects as dominant as ants in such a tropical forest; only the individuals which come out of the nests are affected by the application of DDT, the immature stages inside the nests are not touched.

Unlike the trees treated in the foregoing experiments, in practice, treated cacao trees cannot be completely isolated from giant and other forest trees and climbers containing nests of *Crematogaster* ants which provide a continuous source of large populations.

Several attempts were made to locate the queen ant on cacao; a large number of dead cacao branches were dissected, but no queens could be found, although an African assistant found one in a cell in a big dead cacao branch lying on the

ground. Workers and immature stages were found when dead cacao branches on trees were dissected. These immature stages must have been produced by a queen living away from these branches and been carried there by the workers to form subcolonies of the original colony.

As the complete practical elimination of *Crematogaster* ants was not possible, it was thought that a much smaller application of dimefox by the soil treatment method than the normal one based on the girth-weight correlation (described in previous work, Hanna, Judenko & Heatherington, 1955) might be sufficient if supplemented by a partial control of ants. Experiments were carried out to investigate this possibility.

- (a) The dead branches of cacao trees, containing nests of ants, were cut out and a ring round the trunk one foot above the soil was painted with DDT to prevent ants from climbing the trees. In addition, the trees were watered with 0.8 gm. dimefox active material per inch of girth (about $\frac{1}{3}$ of the normal dosage based on the girth-weight correlation).
- (b) Dead branches were cut off and the trees were watered with 0.8 gm. dimefox active material per inch of girth.
- (c) Trees were watered with dimefox at the rate of 0.8 gm. per inch of girth and no other action was taken.

Eight trees of about 11 inches girth were used for each treatment. The results six weeks after treatment are shown in Table VI.

TABLE VI.

Treatment	No. of mealybugs alive in 80 colonies—10 per tree		Size of population as a percentage of that before treatment
	Before treatment	6 wks. after treatment	
(a)	1111	57	5.1
(b)	1193	49	4.1
(c)	953	67	7.0

The partial elimination of ants does not seem to have increased the efficiency of dimefox when applied to the soil.

The Relation between the Population of Mealybugs and Ants.

It was noticed, during the selection of trees for various experiments, that the number of mealybugs in cacao trees seemed to be in proportion to the number of *Crematogaster* ants. Trees were usually free from mealybugs if no ants could be found on them. The examination of isolated cacao trees with different sizes of dead branches containing nests of ants suggests that the number of mealybugs is in proportion to the size of the nests (Table VII).

It has already been recorded that nests of ants on cacao trees usually occur in dead branches. It may be that there is a correlation between mealybug population and cacao Mirids because the fungal attack that develops from the lesions caused by the Mirids brings about the death of branches, but further work is required to elucidate this point.

Discussion.

The experiments show that in completely isolated mature cacao trees in the field it was possible to eliminate *Crematogaster* ants attending the mealybugs.

This brought down the mealybug population to a very low level. When the ants are excluded, the honeydew secreted by the mealybugs is not removed from the tents, but accumulates and eventually becomes a medium for different species of fungi and other micro-organisms. The cause of the mealybug death is not yet understood, but it may be due to one or more of the following factors:—

- (a) Some of the fungi and other micro-organisms cultured in the honeydew may be parasitic on mealybugs.
- (b) The accumulation of honeydew causes the blocking of the spiracles and the mealybugs are killed by suffocation.
- (c) The accumulation of honeydew and the growth of fungi and other micro-organisms may have a detrimental physiological effect on the mealybugs.

TABLE VII.

Description	Tree no.	Girth (in.)	No. of mealybugs on the trees
Trees with no dead branches	1	7	0
	2	8	0
Trees with small dead branches containing very small ant nests	1	4	12
	2	5.5	7
Trees with medium dead branches containing medium-sized nests	1	7	231
	2	6.5	153
Trees with very big dead branches containing very big ant nests	1	6.5	480
	2	9	553
	3	8	553

Strickland (1951), in an experiment on twenty (six-months-old) cacao seedlings each artificially infested with four young adult females of *P. njalensis*, and kept under controlled conditions in the insectary, found that mould did not seem to interfere with their reproduction and multiplication. J. A. Bond and G. D. Percival (Investigations on the Chemical Control of Coffee Mealybug; *Planococcus kenyae* (Le Pelley) and its attendant ant in Kenya: unpublished report to the Coffee Board of Kenya, 1954), found that the mealybugs very rarely survived on mature coffee trees in the field when the attendant ants, *Pheidole punctulata* Mayr, were completely controlled, unless a great deal of sucker growth was present on which they are particularly persistent. In the insectary, however, mealybugs were found in the present series of experiments to breed up rapidly on seedlings in spite of the complete absence of ants.

There is no detailed analysis of the sugars and other constituents, or their concentrations, exuded from mealybugs living on suckers or seedlings compared with those living on mature cacao or coffee trees. In the absence of such data, the cause of this differential effect cannot be determined with any degree of certainty. It is only possible, at present, to suggest that:—

- (a) The concentration or the chemical composition of the exudations in the two cases may differ. This may cause a selectivity in the growth of a certain parasitic fungus or micro-organism in one case and not the other.
- (b) The concentration of the sugars produced by mealybugs living on mature trees may be higher than that on seedlings, and this concentration may possibly be injurious to mealybugs.
- (c) The presence of mould, in the absence of ants, inside the colonies living on seedlings, where the mealybugs are not affected, and also on the

mature trees, where they are greatly reduced in number, suggests that mould may not cause the death of the mealybugs.

More work is needed to throw some light on this problem.

The method of controlling the cacao mealybugs by controlling the attendant ants, while interesting from an academic point of view, was not found to be practicable on a large scale. Cacao is grown under shade trees and in good cacao farms the canopy of the cacao is continuous. The shade trees, fallen stumps, cracks and crevices could all harbour nests of *Crematogaster* ants, which could not be easily detected and, under the conditions in which cacao is grown in the Gold Coast, it does not seem possible to visualise that the ants could be exterminated.

Summary.

The most important species of Pseudococcid transmitting the swollen-shoot virus disease in the Gold Coast is *Pseudococcus njalensis* Laing. It is almost always attended by ants of the genus *Crematogaster*. These ants usually build their nests in the cavities and galleries that have already been excavated by wood-boring insects in the dead branches of cacao trees. The only apparent advantage of this association to the ants is to imbibe the honeydew secreted from the anal orifice of the mealybugs; if this is allowed to accumulate it becomes a medium for bacteria and fungi which seems to kill the mealybugs eventually.

Attempts were made to break the link between the mealybugs and ants by spraying six cacao trees, not in contact with each other or any other trees, each with 3.5 litres of 0.2 per cent. DDT emulsion, twice at two-week intervals. All dead branches containing nests of ants were cut out, and a band of grease painted, on the trunk, one foot above the soil level to prevent the ants climbing up. Four weeks after the first application of spray, the population of mealybugs was brought down to 1.2 per cent. of its size before treatment. Unfortunately locating the ant nests, especially in the crevices and under the bark, is very difficult. Experiments were therefore carried out in which the trees were sprayed without previously eliminating all the sources of ants. The results were unsatisfactory, the size of the mealybug population, compared with that before treatment, after four, six and eight weeks was 16.9, 39.4 and 92.3 per cent., respectively, in the case of 0.2 per cent. DDT emulsion, and 11.6, 64.3 and 58.8 per cent., respectively, in the case of a treatment consisting of 3.5 litres per tree of a mixture of 0.2 per cent. DDT and 0.02 per cent. parathion active material. Cutting off the dead branches containing ant nests, followed by either painting the cut end of the dead branches with DDT (16.7 per cent. emulsion) or painting the trunk with a band of the same emulsion also gave poor results.

The unsatisfactory results obtained by spraying are attributed to the fact that only the ants that happen to be exposed are affected by the application of the insecticide; the immature stages inside the nests are not touched.

The efficiency of dimefox when applied to the soil at 0.8 gm. active material per inch of tree girth was not increased when the ants had previously been partially eliminated.

Treated cacao trees could not in practice be completely isolated from forest trees and climbers containing nests of *Crematogaster* ants and these provide a continuous source of large populations. It is, therefore, considered that the complete elimination of ants is not possible.

It was also found that there is a relationship between the population of mealybugs and ants. Trees were usually free from mealybugs if no ants were found on them. The examination of isolated cacao trees with different sizes of dead branches containing nests of ants suggests that the number of mealybugs is in proportion to the size of the nests.

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References.

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HANNA, A. D., JUDENKO, E. & HEATHERINGTON, W. (1955). Systemic insecticides for the control of insects transmitting swollen shoot virus disease of cacao in the Gold Coast.—Bull. ent. Res., **46**, pp. 669–710.
- STRICKLAND, A. H. (1951). The entomology of swollen shoot of cacao. II. The bionomics and ecology of the species involved.—Bull. ent. Res., **42**, pp. 65–103.
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FIG. 1.



FIG. 2.

FIGS. 1 and 2. Small cacao trees covered with rain-proof roofs.

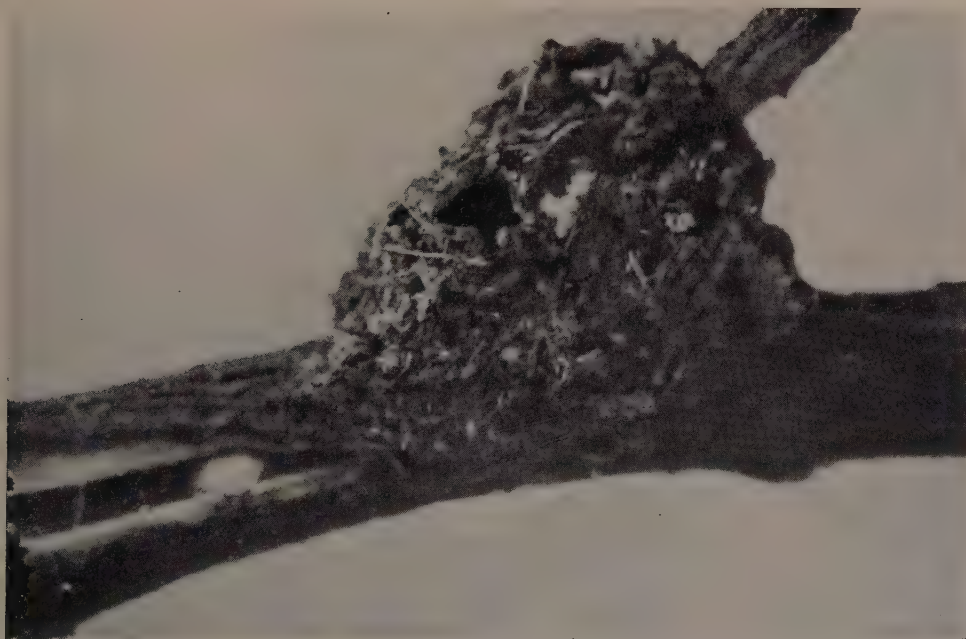


FIG. 3. Ant tent showing the small opening by which the *Crematogaster* ants enter.

2
A STUDY OF FACTORS DETERMINING THE DISTRIBUTION
OF THE LARVAE OF THE BLACKFLY,
SIMULIUM ORNATUM MG.

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In their natural habitat, Simuliid larvae occur in the faster flowing parts of streams. This type of distribution has been explained on the basis of high oxygen concentration (Hubault, 1927) and current speed (Wu, 1931). There is, however, a certain amount of conflict on the relative importance of these factors. The present work was therefore undertaken to study the effects of these factors on the distribution of larvae of *Simulium ornatum* Mg. These were obtained from Sherburn Beck near Durham City, where all field experiments were made; and where, during general investigations, the present writer found larvae in waters of 44 per cent. oxygen saturation at 13.2°C.

Effect of Moving Water on Larvae.

Larvae of *S. ornatum* could be kept alive for periods of up to 14 days in standing water. Two types of experiment were made to test the importance of moving water to the viability of larvae. In one case movement was produced by placing the experimental vessel on a rotating platform, the control remaining stationary. Wu (1931) used petri dishes sealed by heavy, greased glass plates. Grooved perspex lids replaced the glass plates in the present experiments (fig. 1).

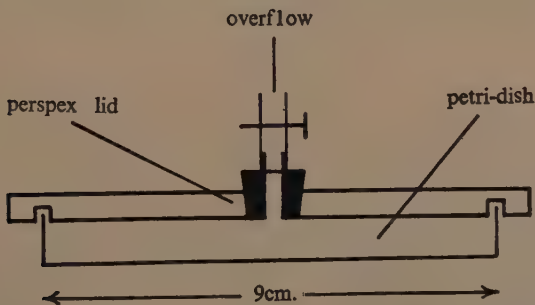


Fig. 1.—Dish used in first type of experiment for testing the importance of moving water to the viability of larvae.

The dishes, 9 cm. in diameter, were filled with water of low oxygen content (Table I) and ten larvae placed in each. Each dish was then sealed. Dish M was placed at the centre of a platform rotating at one revolution per second and dish S on a standing platform. Each experiment lasted 16 to 24 hours, observations being made at two-hourly intervals until all larvae in one dish were dead. Oxygen concentrations were determined by the micro-method of Fox & Wingfield (1938).

TABLE I.

Results of first type of experiment to test the effect of moving water on the viability of larvae. Initially 10 larvae in each dish.

Expt. no.		No. of larvae alive after 16 to 24 hr.	Oxygen concentration (% saturation)		Temp. range (°C.)	Oxygen consumption (cc./gm. wet wt./hr.)
			Initial	Final		
1	M.	0	24	19	17.6-19.7	0.359
	S.	0	18	15		0.122
2	M.	0	26	20	16.8-17.7	
	S.	0	24	12		
3	M.	0	37	30	13.5-14.5	0.423
	S.	1	35	34		0.100
4	M.	0	46	31	14.1-14.6	0.365
	S.	1	38	31		0.171
5	M.	0	32	24	14.6-15.4	0.355
	S.	0	37	26		0.331

M = moving water; S = standing water.

The results (Table I) show that larvae lived for approximately the same length of time in both dishes, but that larvae in moving water had a higher oxygen consumption per gramme wet weight than those in standing water (for Analysis of Variance, which shows significance at the 0.05 level, see Table II).

TABLE II.

Analysis of variance of results of oxygen consumption of larvae given in Table I.

Source of variations	Sum of the squares	Degrees of freedom	Variance estimate
Between samples	0.0755	1	0.0755
Within samples	0.0353	6	0.0059
Total	0.1108	7	

In the second type of experiment, agitation by means of a metal strip operated by an electric current caused water movement. The apparatus (fig. 2) consisted of two glass tubes each of 50 ml. capacity and containing a jointed nickel strip. The strip in M was kept in motion, that in S was maintained at rest. The tubes were filled with water of high oxygen content and ten larvae were introduced into each, which was then tightly sealed. A third tube identical with M and S was

used to record water temperatures during the course of each experiment. Oxygen concentrations were determined as before.

The results (Table III) show that larvae lived longer in standing water than in

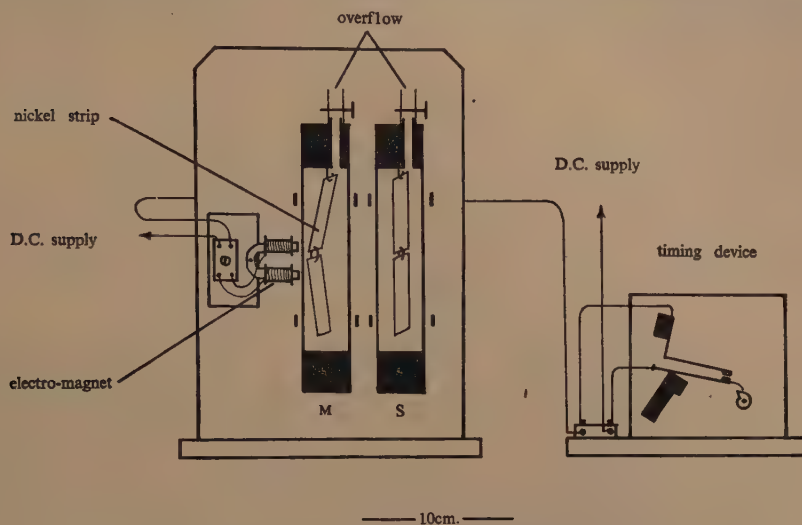


Fig. 2.—Apparatus used in second type of experiment for testing the importance of moving water to the viability of larvae.

moving water in three experiments and for the same length of time in two. The differences in oxygen consumption expressed as cc./gm./hr. were not significantly different at the 0.05 level.

TABLE III.

Results of second type of experiment to test the effect of moving water on the viability of larvae. Initially 10 larvae in each tube.

Expt. no.		No. of larvae alive at end	Oxygen concentration (% saturation)		Temp. range (°C.)	Oxygen consumption (cc./gm. wet wt./hr.)
			Initial	Final		
1	M.	0	155	24	15.0-19.6	0.619
	S.	2	155	27		0.797
2	M.	0	112	15	17.6-22.9	0.819
	S.	0	100	25		0.613
3	M.	0	120	35	14.6-20.5	0.787
	S.	0	102	29		0.605
4	M.	0	87	22	12.1-19.2	0.988
	S.	3	93	25		0.616
5	M.	0	80	12	12.0-19.2	1.284
	S.	5	84	40		0.722

Choice Tests on Reactions of Larvae to Oxygen Concentrations.

The reactions of larvae to different oxygen concentrations were tested in the following way. The apparatus (fig. 3) consisted of a perspex trough, $30 \times 5 \times 5$ cm., down the centre of which a perspex partition divided two-thirds of the trough

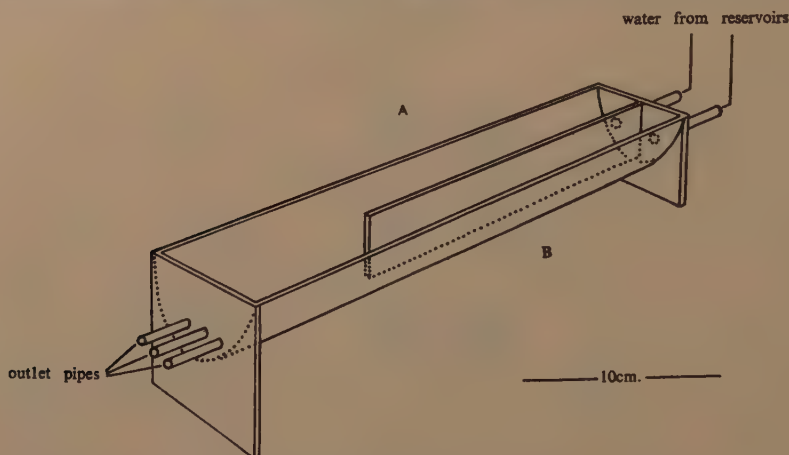


Fig. 3.—Apparatus used in testing the reactions of larvae to different oxygen concentrations.

into two compartments, A and B. Into each compartment an inlet pipe opened, each connected to a reservoir containing water of different oxygen concentration for individual experiments. Three outlet pipes ensured that the velocity of the water leaving the trough was not greater than that entering it so that if, as

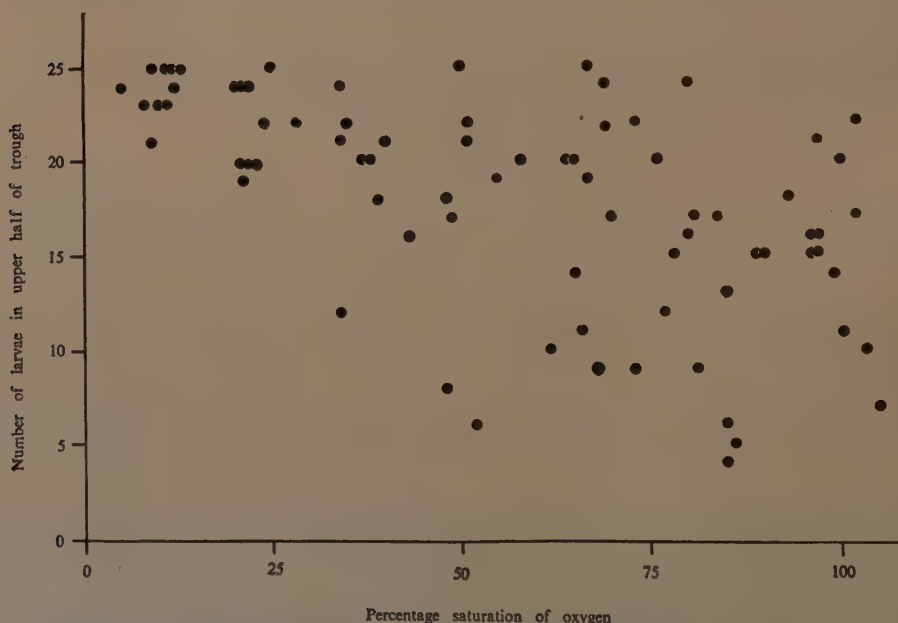


Fig. 4.—Graph showing the number of larvae remaining in the upper half of the trough, plotted against percentage oxygen saturation.

Wu states, the larvae prefer fast currents they would not be attracted down the trough by current speed. All experiments were carried out between water temperatures of 14 to 19°C.

Twenty five larvae were placed in the upper half of each compartment and allowed to attach themselves. At the beginning of each experiment the rate of inflow was adjusted so that it was the same in each compartment (70 to 100 cm./sec.). Illumination was uniform, from above. Each experiment lasted one hour. Oxygen determinations using the micro-method of Fox & Wingfield (1938) were made at the beginning and at 15-min. intervals in case the oxygen content fluctuated. In these and all subsequent experiments the oxygen concentration is expressed as percentage saturation calculated from the nomogram in Ricker (1934).

At the end of an experiment the number of larvae remaining in the upper half of each compartment was counted and plotted against the oxygen concentration of the water flowing over them (fig. 4). These results indicate that larval

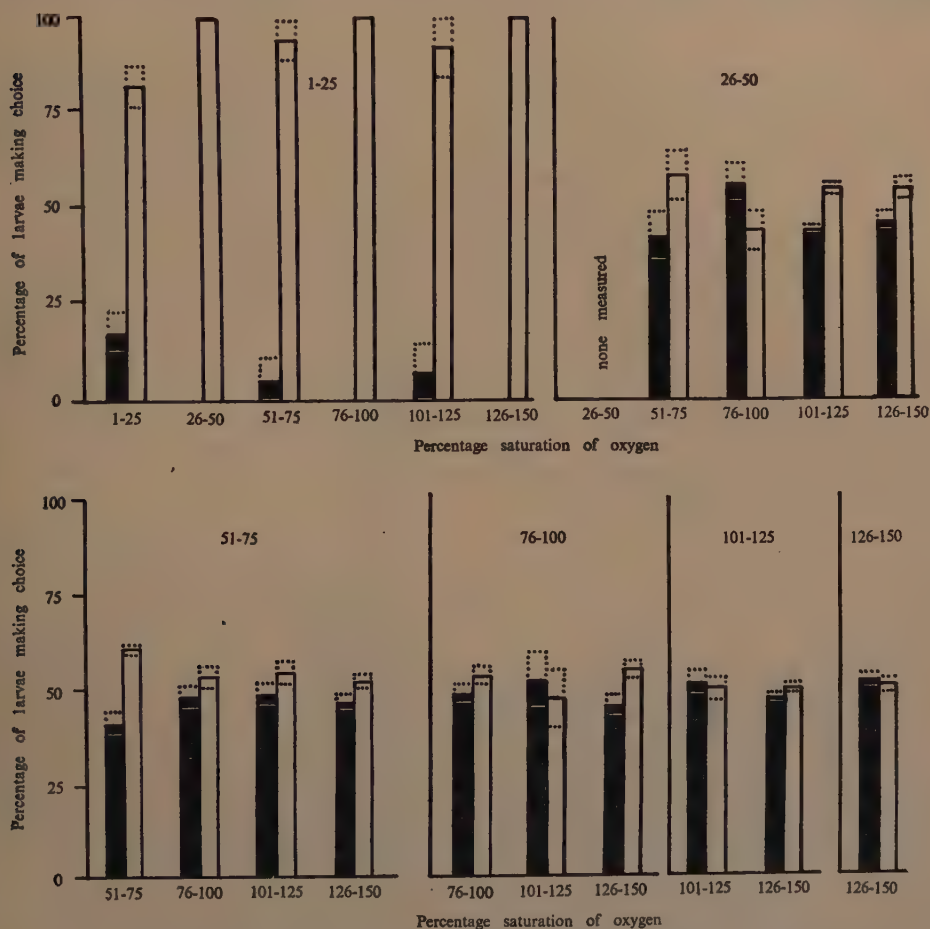


Fig. 5.—Histograms showing the percentage of total numbers of larvae moving into each of two choices of oxygen concentration. One choice is given at the top of each set of histograms and the other on the abscissa. Each black column represents the percentage of larvae moving into the oxygen concentration shown at the top of the histogram, each open column the percentage moving into the oxygen concentration shown on the abscissa. The dotted lines represent the standard deviation for each set of figures.

movement was completely independent of oxygen concentration above 50 per cent. saturation, partially restricted between saturation values of 35–50 per cent. and much restricted below 35 per cent. saturation. All experiments were carried out in the temperature range 16–20°C.

Thirty experiments were carried out to determine whether larvae moved from low oxygen concentrations to high ones. A modified form of the apparatus shown in fig. 3 was used. One-third of the trough near the outflow end was painted black and covered with a black lid. Larvae placed in this region showed a positive phototactic response and moved towards the openings of the two compartments (not darkened) where they were offered a choice of waters of different oxygen concentration. Fifty to a hundred larvae were used in each experiment, of one hour duration. Velocities through the two evenly illuminated compartments were the same. Oxygen determinations were made as in the previous experiment.

At the end of an experiment the number of larvae that had moved into the upper half of each compartment was counted. Results are shown in fig. 5. Temperature range was as before.

Oxygen concentration did not affect larval movement above the 25 per cent. saturation level, as can be seen from the 50:50 distribution of larvae in the two compartments, above this figure.

It was not possible to control the lower oxygen concentrations with accuracy. Thus taking the first example shown in fig. 5, where the behaviour of the larvae was tested in apparently equal oxygen concentrations of 1–25 per cent. saturation it will be seen that the distribution of the larvae between the two compartments was not 50:50 as might have been expected. This anomaly can possibly be explained when actual figures for oxygen saturation are considered. The two experiments, from the results of which the 1–25:1–25 histogram is built, gave larvae a choice of 11 per cent. against 16 per cent. saturation, and 16 per cent. against 25 per cent. saturation. In each case the higher percentage of larvae (88 and 77 per cent. respectively) moved into the higher oxygen concentration. It is suggested therefore that at this type of concentration (25 per cent. saturation and less) larvae were extremely sensitive to slight differences in oxygen concentration and were able to make a choice.

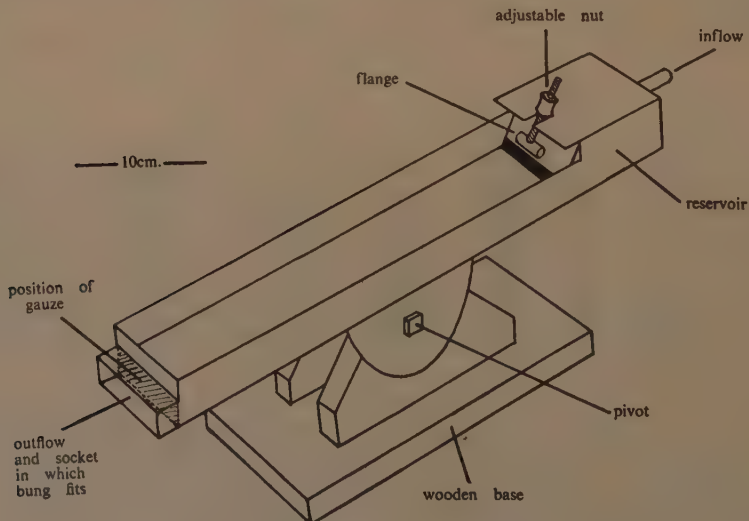


Fig. 6.—Apparatus used to test the ability of larvae to withstand current flow.

Resistance to Speed of Current.

Laboratory experiments.

The ability of larvae to withstand current flow was tested in a trough, $45 \times 5 \times 2.5$ cm. (fig. 6). The reservoir, connected to the tap, ensured a constant head of water. The depth of water in the trough was controlled by adjusting the rubber-edged flange over the inflow. Fine gauze at the outflow prevented loss of larvae. Apparatus was mounted on a wooden base, the angle of the trough to the horizontal being adjustable.

At the beginning of each experiment the trough was horizontal and filled with water, the outlet being closed by a rubber bung. Larvae were introduced and allowed to attach themselves. The water was turned on, the bung removed slowly and the trough inclined at an angle of 30° to the horizontal. After 15 minutes all but five larvae were removed. The speed of current passing over each individual was measured with a fine Pitot tube. Velocity in the first instance was 71 to 100 cm./sec. Each larva was closely watched and the time at which it released its hold was noted. The current speed was increased every 15 min. and recorded. The process was repeated until all larvae had released their hold. Two hundred and two specimens were subjected to this procedure.

The results (fig. 7) show that larvae release their hold at velocities greater than 111 cm. per sec. but retain it at velocities between 71–100 cm./sec.

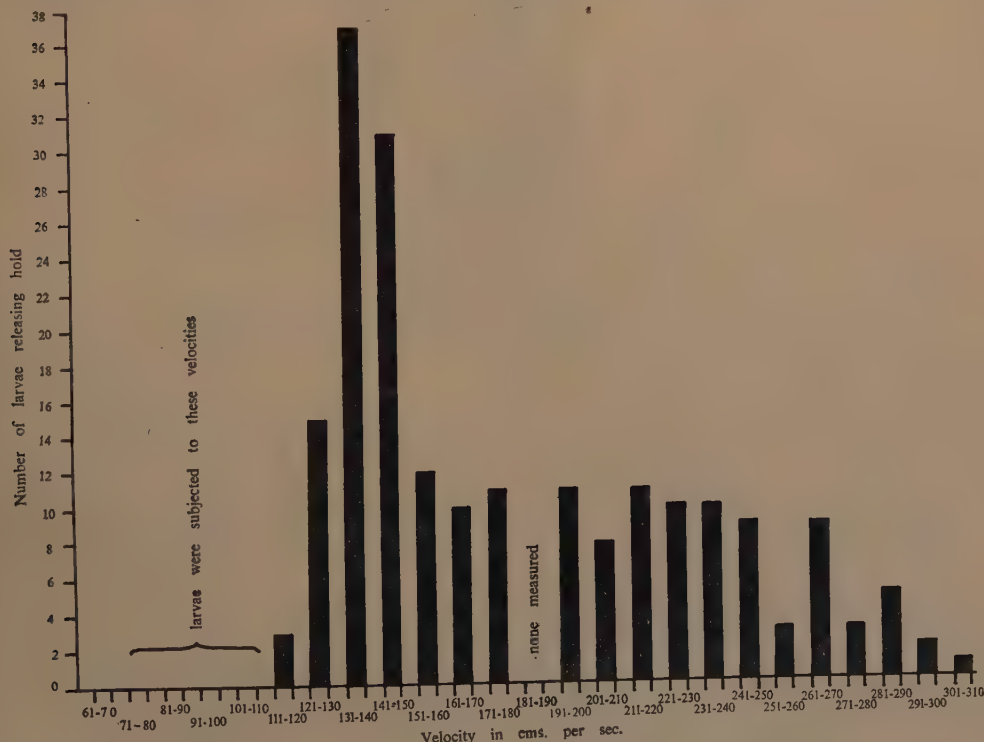


Fig. 7.—Number of larvae releasing hold at high velocities, plotted against velocity in cm./sec. Based on 202 individuals.

In further experiments 98 larvae, after establishing themselves at velocities of 80 to 100 cm./sec., were subjected at intervals of 15 min. to decreases in velocity. Procedure other than change in speed of current was as before.

The results (fig. 8) show that the majority of larvae detach themselves between

velocities of 41 and 70 cm./sec. but remain attached between velocities of 80 and 100 cm./sec.

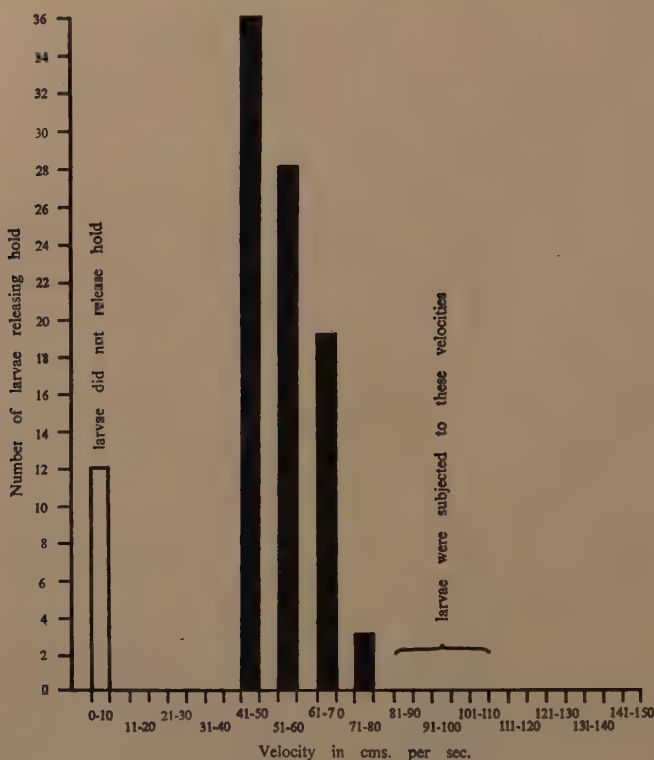


Fig. 8.—Number of larvae releasing hold at low velocities, plotted against velocity in cm./sec. Based on 98 individuals.

Field experiments.

The results of the laboratory experiment having shown that larvae of *S. ornatum* retained their hold over the velocity range of 70 to 110 cm./sec., field observations were then made to see how far the laboratory studies applied to the behaviour of the larvae in their natural habitat.

Solid conical plastic traps with detachable points of equal surface area, to the external surface of which larvae became attached, were placed in different velocities in the stream. The traps were visited at intervals and the speed of

TABLE IV.

Analysis of variance of transformed data shown in fig. 10.

		Degrees of freedom	Sum of the squares	Mean square
Regression	..	2	6.3933	3.1900
Residual	..	5	0.5464	0.0913
Within groups	..	149	54.0360	0.3627
Total	.. ..	156	60.8857	0.3903

current flowing over each was measured with a Pitot tube. Points were removed by quickly pushing them, with a rod, into a tube held over them, thus ensuring a minimum loss of larvae (fig. 11).

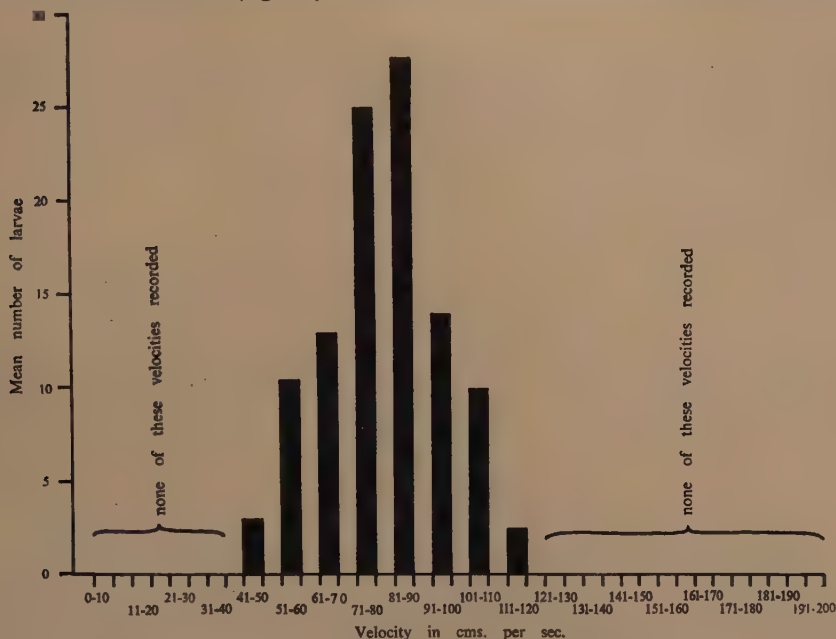


Fig. 9.—Histogram showing the mean number of larvae occurring at known velocities under natural conditions. Based on 2,880 individuals from 158 traps.

The results are based on the examination of 2,880 larvae from 158 traps. The mean number of larvae occurring at each velocity is shown in fig. 9, but as the mean is approximately equal to the standard deviation in each group, a logarithmic transformation has been used. The transformed curve is shown in fig. 10 and the analysis of variance in Table IV.

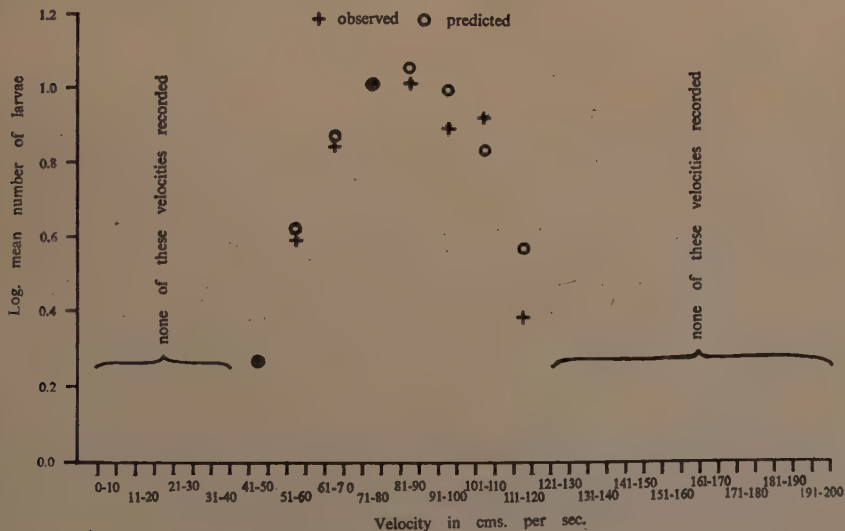


Fig. 10.—Curve of results from fig. 9, after logarithmic transformation.

The results show that the greatest number of larvae occurred in the velocity range 50 to 120 cm./sec., the greatest abundance being at 81 to 90 cm./sec.

Discussion.

Different explanations have been advanced to explain observations such as those of Stannus (1913) who noted a correlation between large numbers of Simuliid larvae in streams and high current velocity. From general field observations Edwards (1920), Puri (1925), Hubault (1927), Smart (1934), Rubtsov

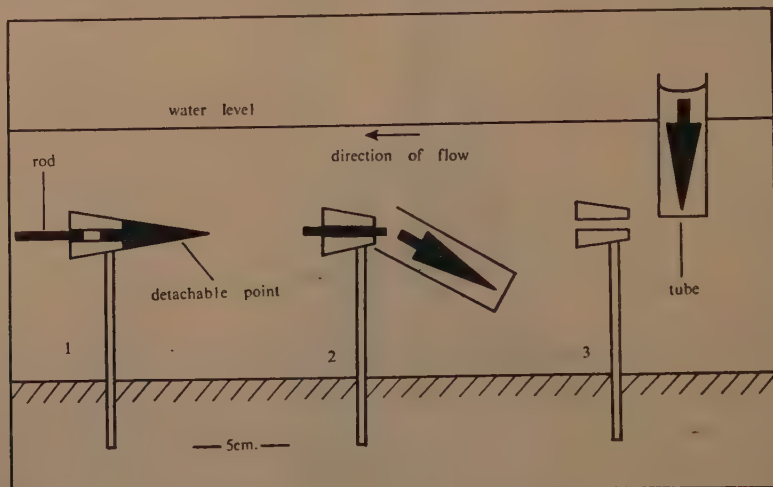


Fig. 11.—Diagram illustrating the removal of trap points in the field.

(1939), Zhivković (1951) and others inferred that velocity enabled larvae to obtain a high oxygen supply. Wu (1931), the first to investigate this problem experimentally, showed that larvae lived for a considerable length of time at low oxygen concentrations and claimed that current velocity was the most important single factor determining distribution. Pacaud (1942) supports the velocity theory as does Zahar (1951), who recorded abundant colonies of *S. ornatum* in oxygen concentrations as low as 48 per cent. saturation at 18°C.

The present laboratory work on larvae of *S. ornatum* shows that they can exist in standing water, thus disagreeing with the view of Galli-Valerio (1927). Field and laboratory work indicates that current speed and not oxygen is the more important of the two factors governing larval distribution in this species.

Experiments on the effect of moving water on larvae show that the larvae tend to die more rapidly in moving water when the oxygen supply is *limited*. These findings oppose those of Wu (1931) but seem reasonable when the oxygen consumption of larvae, under different conditions, is examined. Tables I and II show, and Table III suggests, that larvae in moving water use more oxygen/unit weight/unit time than those in static conditions. The higher oxygen consumption is possibly due to the muscular energy expended by larvae in maintaining their position in moving water. That larvae can exist in standing water and waters of low oxygen content does not mean that they have no preference for currents of certain velocities and/or highly oxygenated waters.

Results of laboratory experiments on the effect of oxygen concentration on larvae of *S. ornatum* indicate that they are not affected by relatively low oxygen concentrations and do not show a preference for highly oxygenated waters. The view that a high oxygen requirement is important cannot be substantiated.

These findings are supported by the field observations of Zahar (1951) and the present writer, who found larvae in waters of 48 and 44 per cent. saturation, respectively; also by the general observations of Grenier (1949), who states that difference in distribution cannot be due to oxygen but some other cause. Oxygen is only a governing factor when there is not enough of it.

Laboratory experiments on the effect of velocity on larvae of *S. ornatum* show that they aggregate in a velocity range of 50 to 120 cm./sec., the greatest number occurring between velocities of 80 to 90 cm./sec. Pacaud (1942) states that larvae of *S. aureum* Fries are most abundant in current speeds of 60 cm./sec. The main advantage accruing from this preference for certain velocities is probably not an increased oxygen supply as stated by Smart (1934), but an increased food supply as hinted at by Tonnoir (1925), and supported by Zahar (1951), who believe that current speed keeps open the mouth brushes.

The present study of *S. ornatum*, both in the field and in the laboratory, therefore, indicates that current speed and not oxygen is the more important of the two factors governing the distribution of the larvae.

In view of the marked variations in the distribution of other species it is important that these conclusions should not be considered as applying to *Simulium* species in general.

Summary.

Field and laboratory studies on the rôle of oxygen concentration and speed of current on larvae of *Simulium ornatum* Mg. show that current speed is more important than oxygen concentration in governing their distribution.

The larvae prefer waters with a velocity range of 50 to 120 cm./sec., the greatest numbers occurring between 80 and 90 cm./sec.

Larvae move independently of oxygen in concentrations above 50 per cent. saturation level.

Acknowledgements.

The writer is indebted to Professor J. B. Cragg and Dr. L. Davies for valuable advice given during the course of the work. Thanks are also due to Dr. E. S. Page for suggestions on the statistical treatment of data.

References.

- EDWARDS, F. W. (1920). On the British species of *Simulium*. II. The early stages; with corrections and additions to Part I.—Bull. ent. Res., **11**, pp. 211–246.
- FOX, H. M. & WINGFIELD, C. A. (1938). Determination of oxygen dissolved in a small volume of water.—J. exp. Biol., **15**, pp. 437–445.
- GALLI-VALERIO, B. (1927). Beobachtungen über Culiciden, nebst Bemerkungen über Tabaniden und Simuliden.—Zbl. Bakt. (Abt. 1., Orig.), **102**, pp. 224–226.
- GRENIER, P. (1949). Contribution à l'étude biologique des simuliides de France.—Physiol. comp., **1**, pp. 165–330.
- HUBAULT, E. (1927). Contribution à l'étude des invertébrés torrenticoles.—Bull. biol., suppl. **9**, 388 pp.
- NICHOLSON, H. P. & MICKEL, C. E. (1950). The Black Flies of Minnesota (Simuliidae).—Tech. Bull. Minn. agric. Exp. Sta., no. 192, 64 pp.

- PACAUD, A. (1942). Notes biologiques sur une station de *Simulium aureum* Fries, aux environs de Paris.—Bull. biol., **76**, pp. 226–238.
- PURI, I. M. (1925). On the life history and structure of the early stages of Simuliidae (Diptera, Nematocera).—Parasitology, **17**, pp. 295–369.
- RICKER, W. E. (1934). A critical discussion of various measures of oxygen saturation in lakes.—Ecology, **15**, pp. 348–363.
- RUBTSOV, I. A. (1939). Factors of outbreaks of the Black-flies. [In Russian with English summary.]—Trav. Acad. milit. Méd., **19**, pp. 177–207. (From Grenier, 1949.)
- SMART, J. (1934). On the biology of the Black Fly, *Simulium ornatum*, Mg. (Diptera, Simuliidae).—Proc. R. phys. Soc. Edinb., **22**, pp. 217–238.
- STANNUS, H. S. (1913). Pellagra in Nyasaland (second communication).—Trans. Soc. trop. Med. Hyg., **7**, pp. 32–56.
- TONNOIR, A. L. (1925). Australasian Simuliidae.—Bull. ent. Res., **15**, pp. 213–255.
- WU (Yi-fang) (1931). A contribution to the biology of *Simulium* (Diptera).—Pap. Mich. Acad. Sci., **13**, pp. 543–599.
- ZAHAR, A. R. (1951). The ecology and distribution of Black-flies (Simuliidae) in south-east Scotland.—J. Anim. Ecol., **20**, pp. 33–62.
- ZHIVKOVIĆ, V. (1951). Le développement de *Simulium salopiense* Edw. 1927, son élevage au laboratoire à partir de l'oeuf jusqu'à l'insecte adulte. [In Serbian with French summary.]—Glas srpsk. kralj. Akad., **204**.
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THE IDENTITY OF SOME EAST AFRICAN SPECIES OF
SAISSETIA (HOMOPTERA, COCCIDAE).

By G. DE LOTTO

Department of Agriculture, Kenya.

Nearly 800 species of Coccids have been described or recorded from the African continent south of the Sahara. Many of the descriptions—and this is especially true of those by the earliest workers—are nowadays utterly inadequate, and the necessity for a better knowledge of these insects in the light of modern concepts is well recognised by systematists and biologists. Through recent papers published by Ferris, Morrison, Hall, McKenzie, etc., many species—among them some of great economic importance—have been excellently redescribed and figured, but still a good many need an appropriate diagnosis using structural characters by which they can be satisfactorily identified.

In the case of some of the important genera such as *Saissetia*, *Coccus*, *Ceroplastes*, *Pulvinaria*, etc., fresh and first-class material is being accumulated at the laboratories of the Department of Agriculture, from Kenya and other parts of Africa and will be dealt with in a series of brief papers.

The main objective of this paper is to settle the identity of a few of the endemic species of *Saissetia*, which although rather common in East Africa, sometimes even on cultivated plants, have been almost completely neglected since their discovery. The description of one new species recently collected in Kenya is included in order to improve the knowledge of the relationship among the African representatives of the genus *Saissetia*. There are other species apparently new but these will be retained for further study, either because the material so far collected is scanty or because they are so close to species already described as to make it advisable to examine the types.

The genus *Saissetia* itself requires more satisfactory taxonomic definition but no attempt is made to do this here.

Altogether seven valid species are dealt with in the present paper, while one—*Saissetia cuneiformis* Leonardi—is sunk as a synonym of *S. nigra* (Nietn.). A provisional key to the species is as follows:—

- (a) legs provided with an articulatory sclerosis
 - (b) dorsal setae stoutly conical
 - (c) dorsal tubercle-like pores few and arranged in a more or less close group in front of the anal plates; submarginal tubercles always present *oleae* (Bernard)
 - (cc) dorsal tubercle-like pores very numerous and most of them loosely distributed on both sides of the anal plates; submarginal tubercles normally absent ... *persimilis* (Newstead)
 - (bb) dorsal setae narrowly spiniform
 - (d) ventral submarginal tubular ducts all of the same size *pterolobina*, **sp. n.**
 - (dd) tubular ducts of two different sizes *hemisphaerica* (Targioni-Tozzetti)
- (aa) legs with articulatory sclerosis absent
 - (e) derm of the dorsum with oval or circular areolations
 - (f) spines of the marginal fringe somewhat flattened and fimbriate at the apex; submarginal tubercles present *somereni* (Newstead)

- (ff) spines of the marginal fringe long and spiniform; submarginal tubercles apparently absent *zanzibarensis* Williams
 (ee) derm of the dorsum marked by a polygonal reticulation
nigra (Nietner)

***Saissetia hemisphaerica* (Targioni-Tozzetti).**

Apparently the first record of this species from East Africa was by Lindinger (1913) from Tanganyika on *Encephalartos hildebrandtii*. A few years later Newstead (1917b) recorded it from Kenya without mention of a host-plant and from Uganda on *Aristolochia* sp., on a fern of the genus *Adiantum* and coffee. In the list of the Coccids of Uganda published in the same year by Gowdey (1917), which actually is only a repetition of the species previously mentioned or described by Newstead, *hemisphaerica* is recorded as living on ferns and coffee only.

Though widely spread in East Africa, *S. hemisphaerica* is not very common and the fact that the species is frequently found on coffee may indicate an actual preference for this host.

All specimens from Kenya and Uganda in the collection of the Department of Agriculture, Nairobi, agree in every detail of taxonomic importance with the description and figures published by Ferris (in Zimmerman, 1948).

Material examined.

KENYA. Kiambu, 29.xii.42, on coffee (*C. F. Fox*); Ruiru, 10.vi.53, on *Coffea arabica* L. (*D. J. McCrae*); Nairobi, 5.i.54, on *Psidium guajava* L. (*G. De Lotto*); Nairobi, 22.x.53, on *Sonchus oleraceus* L. (*do.*); Turbo, 16.xi.54, on *Coffea arabica* L. (*D. J. McCrae*); Kitale, 11.xi.54, on *Coffea arabica* L. (*do.*).

UGANDA. Entebbe, 5.x.52, on cycads (*T. R. Odhiambo*); Kampala, 18.i.54, on *Coffea robusta* Linden (*A. P. G. Michelmore*).

***Saissetia nigra* (Nietner) (= *Saissetia cuneiformis* Leonardi, syn. n.).**

This species is spread all over the East African territories, having been recorded from Uganda by Newstead (1911b; 1913; 1917b) and Gowdey (1913; 1917) on *Ficus* sp., *Annona muricata* and coffee; from Kenya also by Newstead (1917b) on an unidentified ornamental shrub and from Tanganyika by Lindinger (1913) on *Flacourtia sapinda*, *Gossypium* sp. and *Inga* sp.

In 1913, Leonardi described *Saissetia cuneiformis* from specimens collected in Eritrea on *Rhus* sp.* and later Newstead (1917b) recorded it from Kenya on *Acokanthera* sp.

Dry and mounted specimens of *cuneiformis* are at hand from Kenya and Eritrea but no character of adequate diagnostic value can be detected by which it can be separated from *nigra*. In *cuneiformis* the spines of the marginal fringe are normally shorter and more broadly flattened at the apex than is usual in *nigra*, and the anal plates tend to be together somewhat wider than long. Yet these characters are not constant and variations occur even among individuals collected on the same branch, and both these characters are occasionally found in typical specimens of *nigra*. Consequently *cuneiformis* is here placed as a synonym of *nigra*, although with some reluctance in view of the habits of the living adults. When fully mature, they are distinguishable from typical *nigra* by being always very strongly convex, conical at times somewhat depressed all along the side, shining black in colour, and they mostly occur on the lignified

* According to Leonardi the host-plant is *Rhus aztechesan*. The writer is not aware of any Eritrean species of this name, and it seems probable that Leonardi confused the name of the locality where the host-plant was collected with its specific name, since Az Techesan—or Az Teclesan—is an African village about 25 miles north of Asmara.

parts of the host-plants or—occasionally—on green twigs and petioles. No specimens have ever been collected on leaves. As has been pointed out by Ferris (*in* Zimmerman, 1948) there is a considerable variation in the size, form and colour of *S. nigra*. This suggests that among these insects there may be some with biological differences even though no adequate systematic differences can be found to separate them.

According to Compere (1931), who visited Eritrea in 1929–30 for investigations on the parasites of the black scale (*S. oleae*), *S. cuneiformis* (= *nigra*) is relatively common there, and this was fully confirmed by observations made by the writer some years ago when he found this form of *S. nigra* to be particularly common on the highlands, roughly between 5,500 and 7,500 ft., where it often ranks as a serious pest. It disappears along the foothills and apparently does not occur in either the eastern or western lowlands. In Kenya, where search has so far been restricted to the area about Nairobi, the insect is also fairly common, although somewhat scarcer than in Eritrea.

Material examined.

KENYA. Nairobi, 29.xi.37, on *Loranthus* sp. (R. H. Le Pelley); Kilifi, 31.vii.42, on "kapok" (*do.*); from a locality not recorded, 7.xi.42, on coffee (collector unknown); Nairobi (Wangige), 2.iii.51, on *Citrus limonia* Osbeck (*G. De Lotto*); Nairobi, 14.iii.51, on *Aberia caffra* Harv. (*do.*); Nairobi, 20.vi.51, on *Ehretia silvatica* Guerke (*do.*); Nairobi, 24.viii.51, on *Carissa edulis* Vahl (*do.*); Mombasa, 29.viii.51, on *Annona chrysophylla* Boj. (R. H. Le Pelley); Nairobi, 10.x.51, on *Erythrococca* sp. (*G. De Lotto*); Nairobi, 26.vi.53, on *Ficus mallotocarpa* Warb. (*do.*); Athi River, 11.x.53, on *Aberia caffra* Harv. (*do.*); Kisumu, 12.iii.54, on *Grewia* sp. (T. J. Crowe); Nairobi, 5.i.55, on *Ulmus* sp. (R. H. Le Pelley).

ERITREA. Adi Ugri, 30.v.52, on *Gymnosporia senegalensis* var. *spinosa* Engl. (*V. Nastasi*); Asmara, 17.iii.54, on *Vitis vinifera* L. (*Andemeschiel Tuoldehaimanot*).

Other unpublished records from Eritrea for material collected by the writer and mostly examined by Dr. W. J. Hall of the Commonwealth Institute of Entomology, are: *Carissa edulis* Vahl, *Casimiroa edulis* Llav. & Lex., *Cordia abyssinica* Hochst., *Croton macrostachys* Hochst., *Euclea kellau* Hochst., *Ficus dekdekena* A. Rich., *F. lutea* Vahl, *F. palmata* Forsk., *F. vasta* Forsk., *Gymnosporia arbutifolia* Loes., *Psidium guajava* L., *Pyrus malus* L., *Rhus abyssinica* Hochst., *Schinus molle* L., *Solanum jasminoides* Paxt., *Sideroxylon oxyacantha* Baill. and *Vernonia amygdalina* Del.

Saissetia oleae (Bernard).

Only through the positive diagnosis of this species published recently by Ferris (*in* Zimmerman, 1948) could the material on hand be properly studied. At the same time this made it also possible to clear up the identity of *S. persimilis*, an endemic species in Kenya, very close to *oleae* with which it can be easily confused.

Besides the specimens from Kenya in the collection of the Department of Agriculture, Nairobi, *S. oleae* has been recorded from Tanganyika by Newstead (1908; 1911a) and Lindinger (1913) on *Erythrina* sp. and *Ficus* sp.; from Uganda by Newstead (1913; 1914) on *Hura crepitans*, and by Gowdey (1913; 1917) on *Chlorophora excelsa*, thus indicating that the species occurs in all three East African territories, but, despite its wide distribution, *S. oleae* is scarce, and massive infestations such as occur in the Eritrean highlands have not been found by the writer in Nairobi, and it seems probable that the species is scarce in the East African territories since it is never regarded as a major pest.

The distribution of *S. oleae* in Eritrea is more or less the same as for *nigra*. The highlands represent the centre of maximum occurrence, but the species

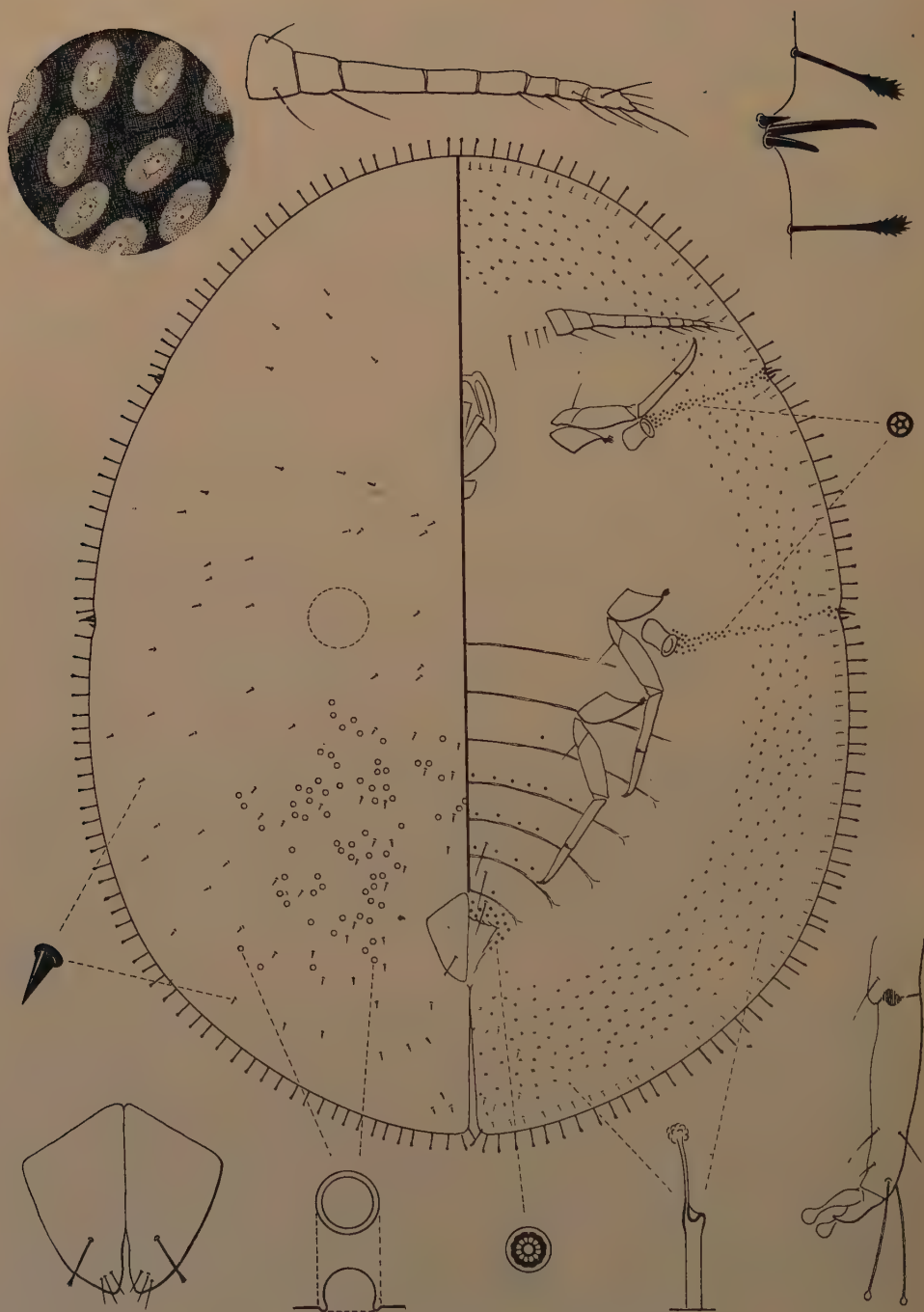


Fig. 1.—*Saissetia persimilis* (Newstead).

becomes less and less common on the eastern and western slopes, and it does not seem to occur in the lowlands.

Material examined.

KENYA. Nairobi, 22.x.51, on *Coffea arabica* L. (G. De Lotto); Nairobi, 12.iii.53, on *Olea europaea* L. (do.); Nairobi, 21.vi.53, on *Markhamia platycalyx* Sprague (do.).

ERITREA. Ghescinascim, 4.iii.53, on *Croton macrostachys* Hochst. (V. Nastasi); Asmara, 19.iii.53, on *Nerium oleander* L. (do.); Asmara, 11.xi.53, on *Poinsettia pulcherrima* Graham (Andemeschiel Tuoldehaimanot).

Other host-plant records not yet published for specimens kindly identified by Dr. W. J. Hall, include: *Acacia cyanophylla* Lindl., *Casimiroa edulis* Llav. & Lex., *Chrysanthemum ? frutescens* L., *Cordia abyssinica* Hochst., *Ficus carica* L., *F. dekdekena* A. Rich., *F. sycomorus* L., *Jacaranda mimosaeifolia* Don., *Psidium guajava* L., *Rhus abyssinica* Hochst., *Vernonia amygdalina* Del. and *Wisteria floribunda* D.C.

***Saissetia persimilis* (Newstead) (fig. 1).**

This species was originally described by Newstead (1917a) from Nairobi, Kenya, on peach stems as a valid species almost identical with *oleae*, except for the different pattern of the areolation of the dorsal dermis. A few years later Brain, in his work on the COCCIDAE of South Africa (1920), reported *persimilis* as occurring on *Combretum* sp. at Muckleneuk, Pretoria, but the knowledge of the real "facies" of the species was in no way improved as he only transcribed Newstead's original description.

Fairly long series of specimens have been collected in the type locality and the following is a redescription of the species. The specimen illustrated was taken on *Nerium oleander* L. at the Scott Agricultural Laboratories, Nairobi.

Young adult specimens identical in colour and form with those of *S. oleae*, being dorsally marked by H-shaped ridges which progressively disappear with growth. Fully mature individuals strongly chitinised, more or less hemispherical but often distorted in relation to the position on the host; surface smooth with very minute lumps of transparent wax; colour very dark brown. Length up to 6 mm.; breadth up to 5 mm., but commonly less.

Specimens examined before chitinisation has set in show the dorsal dermis with numerous, evenly distributed, very small circular pores; some short stoutly conical spines and a large group of up to 150 or more spherical, tubercle-like pores scattered on the postsoma about the anal plates. At full maturity, the dorsum is uniformly areolated by small oval pale areas, each of which encloses one of the minute pores. Anal plates together about as wide as long, with the posterior-lateral margin broadly rounded; each plate is provided with a long fimbriate discal seta and three slender ones at the apex. Submarginal tubercles absent, except in two specimens both provided with two tubercles on one side only. Setae of the marginal fringe practically all of the same size, moderately long, slightly flattened and fimbriated. Stigmatic spines three, of which the median is about two to three times longer than the laterals. Ventral submarginal setae small and slender, inserted in a continuous rather regular line all round the body. Ventral dermis with multilocular disc pores fairly numerous about the vaginal opening and a few, arranged in rows, as far as the attachment of the hind legs. Quinquelocular pores associated with the anterior and posterior spiracles, rather variable in number. Tubular ducts having the inner microduct slender and about half the total length; they are very numerous and occur only in a submarginal band all around the body. Antennae eight-segmented. Legs well developed and provided with an articulatory sclerosis between the tarsus and tibia. Setae between the antennae variable in size and usually not exceeding three or

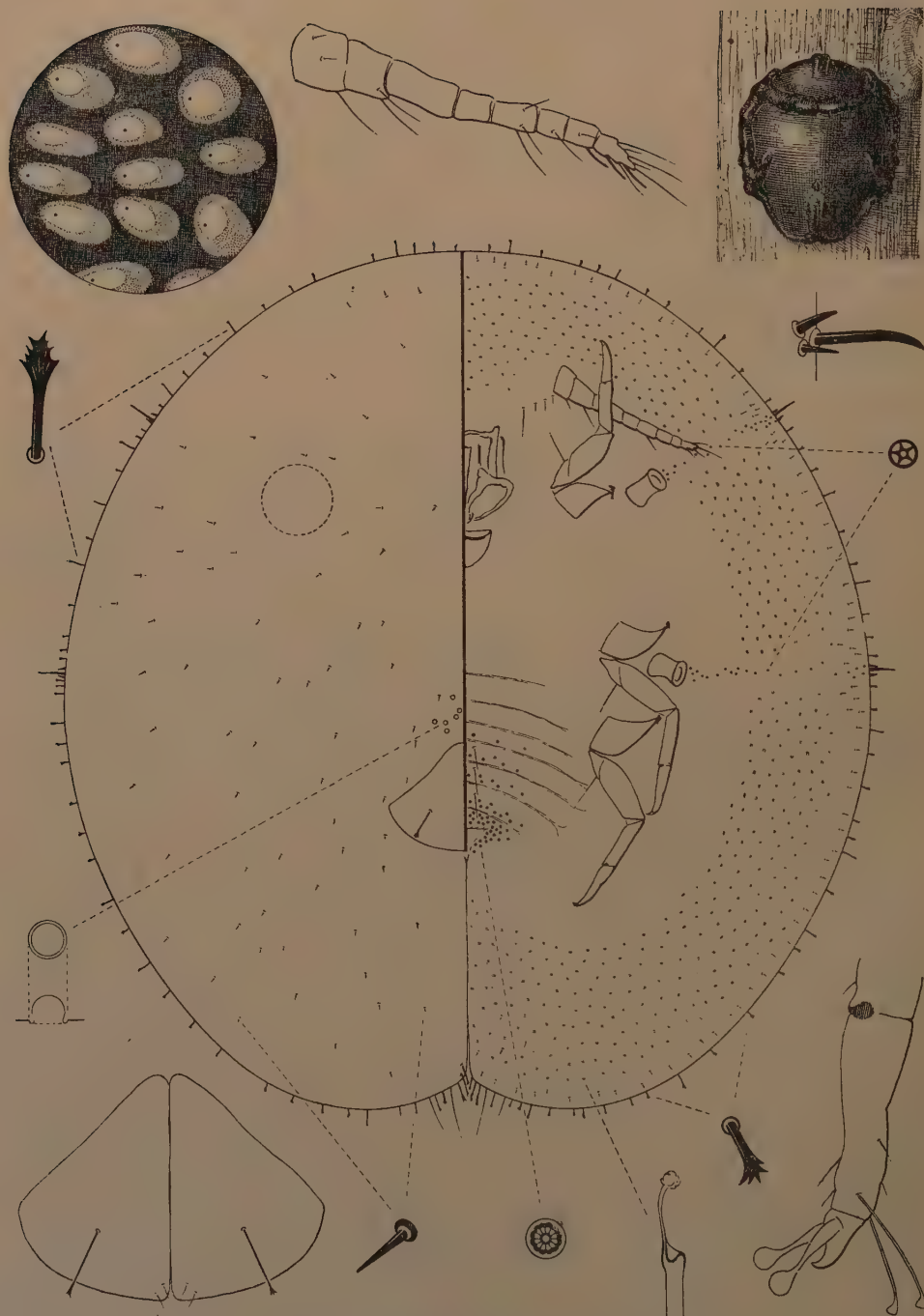


Fig. 2.—*Saissetia pterolobina*, sp. n.

four on each side; setae on the three segments anterior to the vulva long and robust.

Material examined.

KENYA. Nairobi (Kikuyu), 9.iii.51, on *Ehretia silvatica* Guerke (G. De Lotto); Nairobi, 11.iii.53, on *Erigeron bonariensis* L. (do.); Nairobi, 12.iii.53, on *Markhamia platycalyx* Sprague (do.); Nairobi, 12.iii.53, on *Nerium oleander* L. (do.); Nairobi, 14.ix.54, on *Ficus hochstetteri* A. Rich. (do.); Nairobi, 17.xii.54, on *Acokanthera schimperi* Schwf. (do.).

S. persimilis is normally found in the collar of the plant, in crevices, on shoots, etc.; as a rule it attacks the less exposed parts of the host. In Nairobi, this species is much commoner than *oleae*, and in two or three instances the infestations were fairly severe.

As Brain's record on the occurrence of the species in South Africa implies, the distribution of *S. persimilis* covers a wide area and now that its true identity is known it will be certainly reported from many other parts of the African continent.

The slight morphological differences between this species and *oleae* and the different part of plant usually attacked, may be of importance in connection with the parasites of these scales, particularly in view of the past and continuing interest shown by the Californian entomologists in the collection of local parasites for introduction into the United States to control the black scale (*S. oleae*).

***Saissetia pterobolina*, sp. n. (fig. 2).**

Fully mature adults very broadly oval or roughly circular in outline, highly convex and strongly chitinated; dorsum marked by prominent ridges as shown in the accompanying figure; surface polished, with scattered small lumps of glassy wax; colour dark reddish brown with ridges black. Length 3-4 mm.; breadth 3-3.5 mm.

In specimens mounted before the process of chitination of the dermis has begun, many minute circular pores are visible, also some slender spiniform setae and a cluster of 10 to 20 tubercle-like hemispherical pores situated in front of the anal plates. Fully mature specimens marked by small circular or oval unpigmented areas with one of the minute pores near the centre; these areas are distinctly larger towards the margin of the body. Anal plates large, together about one-fourth or one-third wider than long with posterior-lateral margin very broadly rounded, each plate having a rather long discal seta, flattened and fimbriate at the tip and two or three slender apical ones. Submarginal tubercles absent. Marginal spines inconspicuous, of two different sizes, both dilated and fimbriate or dentate at the apex; the longer ones are set widely apart from each other, often at irregular distances, and between them there are a few smaller ones some of which are slightly away from the true margin. On the lip of the anal invagination are inserted four or five spines similar to those of the margin but larger and stouter, and two or three long slender setae. Stigmatic spines three, the median about two or three times longer than the laterals. Ventral submarginal setae small forming an irregular fringe all around the body. Dermis of venter with multilocular disc pores about the vulva and on the three or four preceding segments. Quinquelocular pores few, in a single row. Tubular ducts of usual shape, numerous and arranged in a wide band on the submarginal area. Antennae with eight segments. Legs well developed having an articulatory sclerosis between tibia and tarsus. There are two or three setae, one rather long, near the attachment of the antennae; each of the last three abdominal segments cephalad of the vulval opening with two long setae.

KENYA. Nairobi, 17.xii.54, 15 mounted ♀♀, collected on branches of *Pterolobium lacerans* R. Br. (G. De Lotto).

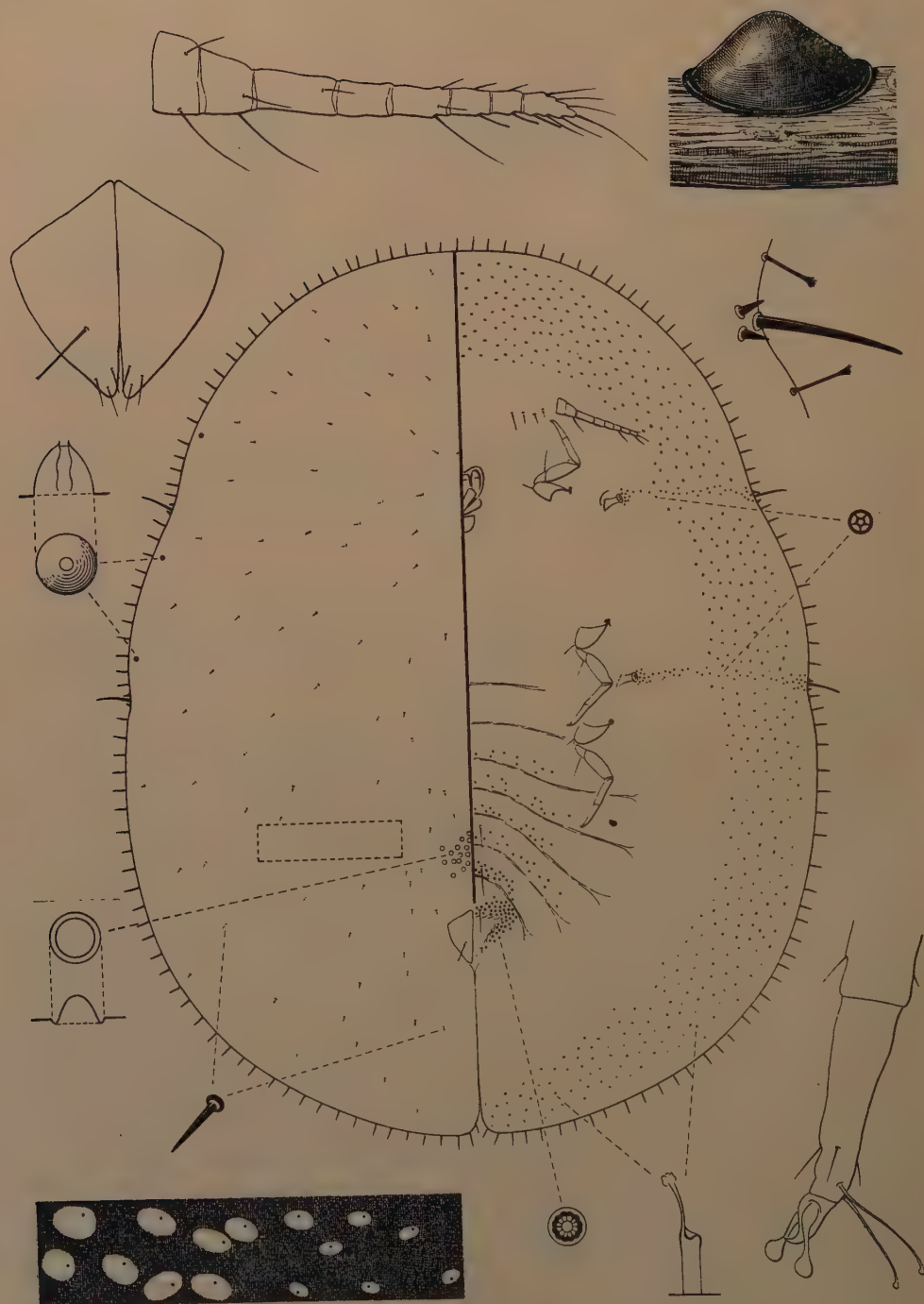


Fig. 3.—*Saissetia somereni* (Newstead).

The holotype will be deposited in the British Museum (Natural History), London, also one paratype in the U.S. National Collection of Coccidae, Washington, D.C., and the remainder in the collection of the Department of Agriculture, Nairobi, Kenya.

By the body structures *S. pterolobina* comes close to *persimilis*, from which it is separable by the different shape of the dorsal setae, the smaller number of dorsal tubercle-like pores and by the shape and size of the anal plates. On living specimens, the pattern of the dorsal ridges easily distinguishes *pterolobina* from any congeneric species so far known from the Ethiopian region.

***Saissetia somereni* (Newstead) (fig. 3).**

First described by Newstead (1910) as a variety of *Lecanium mori* Signoret, from specimens collected on mulberry (*Morus* sp.) in Uganda. The following year Newstead (1911a) described *Lecanium (Eulecanium) tremae* as a new species from Tanganyika on *Trema guineensis* and under the same name he also recorded it (1911b) as occurring in Uganda on an indigenous plant called "nsambyia". Two years later the same author (1913) on examining fresh material of *tremae* came to the conclusion that the two species were identical and sunk *tremae* as a synonym of *mori* var. *somereni* which he raised to specific rank, assigning the species to the section *Eulecanium* of the genus *Lecanium*. Further records from Uganda were published by Gowdey (1913; 1917) on mulberry, *Tecoma stans* and *Dolichandrone* (= *Markhamia*) *platycalyx* and by Newstead (1917b) on *Erythrina excelsa*. Lindinger's record (1913) from Tanganyika is that previously made by Newstead in his original description.

The accompanying figure is based on one individual found on *Croton* sp. in Nairobi.

Adults at full maturity broad or elongate oval, often asymmetric in outline, strongly convex, tending to be conical particularly if living on small branches; margin with a rounded ridge all around the body; dorsal dermis deeply chitinised; colour very dark brown or shining black; surface smooth with lumps of wax. Length 3-4 mm.; breadth 3-3.5 mm. Specimens on leaves are normally somewhat larger but less convex and somewhat narrowed in front, almost deltoid.

In young specimens, in which the dorsal dermis is still membranous, there are several extremely minute circular pores and many slender spiniform setae; tubercle-like pores conical with the vertex rounded, often variable in size and set in a loose cluster of 25 to 45 in front of the anal plates only. In fully mature adults the dorsum becomes very strongly chitinised with small oval or circular pale areas which are more conspicuous along the marginal area. Anal plates together as wide as long or only slightly longer, pointed, with posterior-lateral margin rounded; the discal seta on each, robust and slightly frayed at the apex; apical setae normally four, all slender. Submarginal tubercles 1 to 4 on each side. Spines of the marginal fringe mostly moderately long, more or less equal in size in a single specimen, but rather variable on different individuals even when collected on the same host; apex somewhat flattened and dentate. Setae of the ventral submarginal fringe minute and set at irregular distances, sometimes widely separated. Stigmatic spines three, the median one about four to five times the length of the laterals. Ventral dermis with multilocular disc pores very numerous around the genital opening and extending in rows as far as the second abdominal segment. Quinquelocular disc pores associated with the spiracles numerous. Tubular ducts small but abundant and set in a submarginal band all around the body. Antennae eight-segmented. Legs without articulatory sclerosis. Interantennal setae three or four on each side, one of which rather long. Setae on the three prevulval segments moderately long and robust.

Material examined.

KENYA. Nairobi, 14.iii.51, on *Melia azedarach* L. (G. De Lotto); Nairobi, 20.iv.51, on *Morus* sp. (R. M. Nattrass); Nairobi, 22.v.51, on *Eugenia* sp. (G. De Lotto); Nairobi, 4.v.51, on *Ficus hochstetteri* A. Rich. (do.); Nairobi, 20.vi.51, on *Ehretia silvatica* Guerke (do.); Nairobi, 1.viii.51, on *Markhamia hildebrandti* Sprague (do.); Nairobi, 19.viii.54, on *Croton* sp. (do.); Nairobi, 11.ix.54, on *Flacourtia indica* Burm. f. (do.); Nairobi, 22.ix.54, on *Psidium guajava* L. (R. H. Le Pelley); Nairobi, 8.xii.54, on *Erythrina tomentosa* R. Br. (G. De Lotto).

It is clear from the foregoing list of hosts that *S. somereni* is common in Nairobi and in some cases the plants were found to be so heavily infested that the species is to be ranked as a pest. Although living adults might be confused with those of *S. nigra* they can readily be distinguished with the naked eye, by the presence of the marginal ridge.

Saissetia zanzibarensis Williams.

This species has been described quite recently by Williams (1953) from Zanzibar and Pemba where it is widely spread, attacking *Jambosa caryophyllus*, *Syzygium cumini*, *Jambosa jambos*, *Mangifera indica*, *Canarium commune*, *Persea americana*, *Psidium guajava*, *Cassia* sp., *Gliricidia sepium*, *Averrhoa carambola*, *Cocos nucifera*, *Citrus* sp., *Achras zapotilla*, *Adansonia digitata*, and *Ficus* sp. Five specimens collected on *Mangifera indica* L. in Mombasa kindly presented by Dr. D. J. Williams as well as one specimen collected by Dr. R. H. Le Pelley also in Mombasa on *Mangifera indica* L. on 24.v.51, suggest that the distribution of *S. zanzibarensis* in East Africa covers not only the islands of Zanzibar and Pemba but involves the coastal districts of the continent and extends at least to the immediate inland areas as indicated by the discovery of the species at Mvomero in Tanganyika recorded by Williams in his original description.

Summary.

A systematic review of some species of the Coccid genus *Saissetia* occurring in East Africa led to the rediscovery of two species—*S. persimilis* (Newst.) and *S. somereni* (Newst.)—which although of economic importance have been almost completely neglected since they were first described. Both are redescribed in this paper. One new species recently collected in Kenya is described; this is *S. pterolobina*.

Seven species are dealt with in the paper, including the important and widely distributed *S. oleae* (Bern.). A provisional key for their separation is included, while one species—*S. cuneiformis* Leonardi—is sunk as a synonym of *S. nigra* (Nietn.).

Acknowledgements.

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References.

- BRAIN, C. K. (1920). The Coccidae of South Africa. V.—Bull. ent. Res., **11**, pp. 1-41.
- COMPÈRE, H. (1931). A discussion of the parasites of *Saissetia oleae* (Bern.) collected in Eritrea.—Univ. Calif. Publ. Ent., **5**, pp. 247-255.

- GOWDEY, C. C. (1913). A list of Uganda Coccidae and their food-plants.—Bull. ent. Res., **4**, pp. 247–249.
- GOWDEY, C. C. (1917). A list of Uganda Coccidae, their food-plants and natural enemies.—Bull. ent. Res., **8**, pp. 187–189.
- LEONARDI, G. (1913). Contribuzione allo studio delle cocciniglie dell' Eritrea (Africa orientale).—Boll. Lab. Zool. Portici, **7**, pp. 27–38.
- LINDINGER, L. (1913). Afrikanische Schildläuse. V. Die Schildläuse Deutsch Ost-afrikas.—Jb. hamburg. wiss. Anst., **30**, 3. Beih., pp. 59–100.
- NEWSTEAD, R. (1908). Coccidae. In Sjöstedt, Y. Kilimandjaro–Meru Expedition, **12**, pt. 1, 10 pp.
- NEWSTEAD, R. (1910). Some further observations on the Scale Insects (Coccidae) of the Uganda Protectorate.—Bull. ent. Res., **1**, pp. 185–199.
- NEWSTEAD, R. (1911a). On a collection of Coccidae and Aleurodidae, chiefly African, in the collection of the Berlin Zoological Museum.—Mitt. zool. Mus. Berl., **5**, pp. 153–174.
- NEWSTEAD, R. (1911b). Observations on African Scale Insects (Coccidae) (no. 3).—Bull. ent. Res., **2**, pp. 85–104.
- NEWSTEAD, R. (1913). Notes on Scale-insects (Coccidae). Part I.—Bull. ent. Res., **4**, pp. 67–81.
- NEWSTEAD, R. (1914). Notes on Scale-insects (Coccidae). Part II.—Bull. ent. Res., **4**, pp. 301–311.
- NEWSTEAD, R. (1917a). Observations on Scale-insects (Coccidae). III.—Bull. ent. Res., **7**, pp. 343–380.
- NEWSTEAD, R. (1917b). Observations on Scale-insects (Coccidae). V.—Bull. ent. Res., **8**, pp. 125–134.
- STEINWEDEN, J. B. (1929). Bases for the generic classification of the Coccoid family Coccidae.—Ann. ent. Soc. Amer., **22**, pp. 197–245.
- WILLIAMS, D. J. (1953). On a new species of *Saissetia* (Hem.: Coccoidea) from Zanzibar.—Bull. ent. Res., **44**, pp. 581–582.
- ZIMMERMAN, E. C. (1948). Insects of Hawaii. Volume 5. Homoptera: Sternorrhyncha.—464 pp. Honolulu, Univ. Hawaii Press.
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THE LARVAE OF THE SPECIES OF TINEIDAE OF ECONOMIC IMPORTANCE.

F.M.A.

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Introduction.

Few larvae of the TINEIDAE have been adequately described, and few attempts have been made to construct keys to the species. The most extensive keys previously made are those of Hinton (1943) to seven species and those of Hinton & Corbet (1955) to eight species. The keys given here include 32 species. Of

these, no less than 21 are either indigenous to Britain or are established here, so that keys and descriptions are now provided for half of the known British species of the family.

Representatives of both the ACROLOPHINAE and SCARDIINAE have been included in the key, which thus includes all of the subfamilies of the TINEIDAE at present recognized by Hinton (1955). A few other species which are not yet recorded as pests are also included in this revision. Of these, at least two of the species of *Nemapogon*, *N. ruricolella* (Staint.) and *N. emortuella* (Zell.), will probably sooner or later be found in mouldy grain like their very close relatives, *N. cloacella* (Haw.), *N. granella* (L.), and *N. infimella* (H.-S.).

Larvae of most of the species known to be of economic importance have fortunately been available and are described in detail in the following pages, where brief summaries of their habits are also given. I have not been able to obtain larvae of three species of some importance, namely: *Tineola furciferella* Zagulyaev, *Trichophaga perena* Corbet & Tams, *Monopis crocicapitella* (Clem.), and *M. ethelella* (Newman). Such records as I have gathered of the habits of these three species and a number of others of doubtful status as pests are summarised on pp. 328-329.

The nomenclature of the setae is that of Hinton (1946), which has now come into general use. The terminology of the cranial areas is that of Hinton (1948). The terminology has been criticised by Short (1951) on the grounds that it casts doubt upon the accepted criteria for recognizing the limits of the frons and clypeus in other orders of insects. But, as pointed out by Chiswell (1955), Short's criticisms are based upon a misunderstanding of the problem, which is simply that by using the criteria of homology accepted by Snodgrass and others, the homologies of the cranial areas of the caterpillar head are as described by Hinton (1948).

Lines next to illustrations all refer to 0.22 mm. unless otherwise indicated; and all illustrations accompanied by such lines were drawn with the aid of a camera lucida. All other figures are setal maps. In these maps the relative distances between the setae are correctly shown within rectangles that only approximately correspond to the outlines of the segments: it need hardly be mentioned that it is not possible correctly to draw on a less curved surface both the distances between objects on a more curved surface as well as the outlines of that surface. The setal maps are so orientated that the anterior margin of the segment is always on the left.

References in the descriptions to the right and left sides are to larvae with the dorsal side uppermost and the head directed away from the observer.

It should be stressed that it is necessary to stain and mount the cuticle in order to distinguish all of the setae, especially the microscopic setae of caterpillars as small as those of the TINEIDAE. Unless the cuticle be stained, it is frequently not possible to recognize with any accuracy the shape and arrangement of the pinnacula, which are often most useful in distinguishing genera and species. A satisfactory method is as follows: larvae are immersed in 10 per cent. KOH for two or three days. A slit is first cut along one side from the anus to the anterior margin of the prothorax leaving the head attached and the thorax and abdomen can then be opened out and any tissue that still adheres scraped away. Following this the specimen is washed vigorously in water and afterwards in dilute acetic acid. It is then stained in weak carbol fuchsin for one or two days, which secures much more even staining than using strong carbol fuchsin for shorter periods. After dehydration in the usual way, the head is detached. The thorax and abdomen are spread out and flattened in cedar-wood oil and mounted in Canada balsam. The mouth-parts are removed from the head, and both are mounted separately.

It is important to be able to use the larval cuticle shed on pupation, since this is sometimes the only larval material available of a species. The thorax and

abdomen of such shed cuticles are always crumpled. Mounts can, however, be made from them which are nearly as good as those made from whole larvae. The cuticle is kept for two or three days in 10 per cent. KOH in an open watch glass. During this time the solution absorbs carbon dioxide from the atmosphere, and some carbonates are formed. When the cuticle is soft, acetic acid is added. The carbon dioxide evolved from the carbonates enclosed by the cuticle blows the latter out to its original shape and the thorax and abdomen can then be opened and stained as described above.

Some difficulty may be experienced in making an even cut along the sides, especially in very small larvae. This difficulty can be overcome by making a knife from the edge of a razor blade. The edge is broken off with pliers and inserted in a glass tube of suitable calibre. It is then fastened firmly with sealing wax. The very slender knife thus made is inserted through the anus. A pin held in the other hand is rubbed back and forth on the cuticle over the cutting edge until the cuticle is cut. A cut can thus be made wherever desired without in any way tearing the cuticle, as the knife is not moved during the process of cutting.

Key to the Larvae of TINEIDAE.

1. Head with postgenae nearly fused together on a broad front along median line. Prolegs of segments three to six and ten each with a broad band of spines or smaller crochets above the usual crochets. (Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending less than half of distance to vertical triangle; six ocelli on each side. Spiracles with vertical diameter much greater than horizontal.) ACROLOPHINAE. West Indies
Acrolophus rupestris (Walsingham)*
- Head with postgenae only near each other on a very narrow front. Prolegs (figs. 115, 138, 144, 159, 163, 167, 179, 198) without recurved spines above crochets except in *Lindera* and *Setomorpha* in which there are minute recurved spines above crochets of prolegs of segments three to six but not above crochets of prolegs of tenth segment 2
2. L group of prothorax bisetose (fig. 9). D1 setae on first eight abdominal segments more widely separated than D2 setae (fig. 14). (Head with A1 only about a third as long as A2. L group of ninth abdominal segment bisetose.) SCARDIINAE. Europe *Scardia boleti* (Fabricius)
- L group of prothorax trisetose. D1 setae of first eight abdominal segments less widely separated than D2 setae. Head with A1 about as long or longer than A2. L group of ninth abdominal segment trisetose except in *Tineola* ... 3
3. SV group of meso- and metathorax unisetose. Head usually with five (fig. 51) or six (figs. 64, 70, 73) convex ocellar lenses on each side but sometimes with less than five or none. NEMAPOGONINAE 4
- SV group of meso- and metathorax bisetose. Head never with more than one convex ocellar lens on each side and sometimes with none. TINEINAE 13
4. Head (figs. 26 & 32) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending slightly less to slightly more than half of distance to vertical triangle; each side of head with not more than two distinct ocelli (fig. 33). SV group of first abdominal segment trisetose. (First eight abdominal segments with seta SD2 minute.) 5
- Head (figs. 50, 72) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending two-thirds to four-fifths of distance to vertical triangle; each side of head with five (fig. 51) or six (figs. 64, 70, 73) convex ocellar lenses. SV group of first abdominal segment bisetose 7
5. Prothorax (fig. 28) with L1 below and distinctly anterior to L3. Mandible (fig. 27) with a single large tooth. Head without distinct ocelli (without

* See Hinton (1955).

- convex cuticular lenses but sometimes with a few pigment spots beneath a large pale area of the cuticle which is in the usual position of fourth ocellus. Prolegs of segments three to six with minute recurved spines, resembling minute crochets, above the usual terminal crochets. Spiracles with peritreme black or nearly so. Mature larva 24–28 mm. long. Nearly cosmopolitan
Lindera tessellatella Blanchard
- Prothorax (fig. 36) with L1 directly below L3. Mandible (fig. 34) with three apical teeth in addition to a smaller subapical tooth which is on ventral side of large outer tooth. Head with one or two (fig. 33) convex ocellar lenses on each side. Prolegs of segments three to six without recurved spines above the terminal crochets. Spiracles with peritreme moderately pale brown. Mature larva 12–14 mm. long. *Haplotinea* 6
6. Abdomen with SV1 and SV2 of eighth segment on separate pinnacula. Head (fig. 33) often with two ocellar lenses on each side. Europe
Haplotinea ditella (Pierce & Metcalfe)
- Abdomen with SV1 and SV2 of eighth segment on the same pinnaculum. Head with only one ocellar lens on each side. Europe
Haplotinea insectella (Fabricius)
7. Head (fig. 51) with only five ocelli on each side. L1 and L2 of first eight abdominal segments in a nearly horizontal line with L1 some distance below the spiracle. Prothorax (fig. 58) with SD1 considerably behind XD1 and XD2. Abdomen with nearly all setae of first nine segments arising from very clearly marked (visible to the naked eye) pinnacula. Prothorax with the longest seta of the L group (L1?) nearest to the spiracle and the two most anterior setae in a vertical line (fig. 5). First eight abdominal segments with SD1 and SD2 on the same pinnaculum. Pinnacula of V1 setae of thorax not fused to coxae 8
- Head (figs. 64, 70, 73) with six ocelli on each side. L1 and L2 of first eight abdominal segments in an oblique line with L1 more or less directly behind spiracle. Prothorax (figs. 67, 69, 85) with SD1 more or less in a line with XD1 and XD2. Abdomen with setae of first nine segments not arising from pinnacula which are clearly visible without staining. Prothorax with the longest seta of the L group, i.e. L1, not the nearest to the spiracle and L2 and L1 not in a vertical line. First eight abdominal segments with SD1 and SD2 on the same or on separate pinnacula. Pinnacula of V1 setae of thorax fused to coxae 9
8. Abdomen with D2 of ninth segment on the same pinnaculum as D1 and SD1. Europe *Nemapogon parasitella* (Hübner)
- Abdomen (fig. 63) with D2 of ninth segment not on the same pinnaculum as D1 and SD1. Europe *Nemapogon fulvimitrella* (Sodoffsky)
9. Head (fig. 64) with posterior fourth to third dark brown, often nearly black. (Mandible, fig. 66, very broad and with mesal margin strongly arcuate. Seta L1 separated from second ocellus by two to four or more times the diameter of the ocellus.) 10
- Head with posterior region not darker or if so only with extreme posterior margin darker 11
10. Prothorax (fig. 67) with SD1 twice as far from XD1 as from XD2; sclerotised parts of prothoracic tergite pale yellowish brown. Britain
Nemapogon ruricolella (Stainton)
- Prothorax (fig. 69) with SD1 approximately half way between XD1 and XD2; sclerotised parts of prothoracic tergite moderately dark brown. Europe
Nemapogon emortuella (Zeller)
11. Fuscous eye-spot (fig. 70) extending posteriorly to first two ocelli. Europe (Cosmopolitan?) *Nemapogon cloacella* (Haworth)

- Fuscous eye-spot (fig. 73) not extending beyond third and fourth ocelli in the area between these ocelli and first and second ocelli 12
- 12. Seta L1 behind second ocellus separated from it by less than one to one, or very slightly more than one, diameter of the ocellus (fig. 73). Nearly cosmopolitan *Nemapogon granella* (Linnaeus)
- Seta L1 behind second ocellus separated from it by one-and-a-half to two or more times the diameter of the ocellus. Europe *Nemapogon infimella* (Herrich-Schaffer) *
- 13. Front legs with coxae of right and left sides never fused or nearly fused 14
- Front legs with coxae of right and left sides fused (figs. 190 & 207) or nearly fused (fig. 199). Head usually with a large ocellar lens on each side. Larva always in a flattened, fusiform, portable case 27
- 14. SV group of meso- (fig. 89) and metathorax in a feebly oblique or nearly horizontal line. Ninth abdominal segment (fig. 92) with L group bisetose. First eight abdominal segments with SD2 dorsal and considerably anterior to the spiracle (figs. 90-91). Spiracles of seventh abdominal segment approximately as large as those of eighth abdominal segment. (Head without convex ocellar lenses and usually without pigment spots. Larva not in a portable case.) Cosmopolitan *Tineola bisselliella* (Hummel)
- SV group of meso- and metathorax in a vertical or nearly vertical line. Ninth abdominal segment with L group trisetose. First eight abdominal segments with SD2 more or less directly dorsal to spiracle. Spiracles of seventh abdominal segment only one-half to two-thirds as large as those of eighth segment 15
- 15. L1 and L2 of first seven abdominal segments in a nearly vertical line with L1 directly behind spiracle 16
- L1 and L2 of first seven abdominal segments in a more or less horizontal line with L1 considerably below spiracle 22
- 16. Abdomen (fig. 101) with a distinct median longitudinal carina or ridge on eighth tergite. *Amydria* 17
- Abdomen without trace of a median longitudinal carina on eighth tergite. *Monopis*, *Trichophaga* 18
- 17. Abdomen with D1 of ninth segment (fig. 99) twice as far from D2 as from SD1; median longitudinal ridge of eighth tergite broad and only feebly sclerotised. Africa *Amydria vastella* (Zeller)
- Abdomen with D1 of ninth segment nearly as close to D2 as it is to SD1; median longitudinal ridge of eighth tergite narrow, knife-like, and strongly sclerotised. Africa (Zanzibar) *Amydria* sp.?
- 18. Antenna (fig. 112) with first segment at least as long as second. SD1 of prothorax (fig. 109) nearer to XD2 than is XD1. First eight abdominal segments with SV setae always on separate pinnacul† (fig. 115); SD1 as far, or distinctly further, from spiracle as L1; ninth abdominal segment with D1 and SD1 always on separate pinnacula. Prolegs (fig. 115) of segments three to six with ellipse of crochets nearly always closed on mesal side. Microscopic spines of abdomen (fig. 123) sub-triangular and not produced into long, slender microtrichia. *Trichophaga* 19
- Antenna (fig. 124) with first segment much shorter than second. SD1 of prothorax (figs. 122, 136, 143) slightly further from XD2 than is XD1. First eight abdominal segments with SV setae always on the same pinnaculum (figs. 138, 144); SD1 always nearer to spiracle than L1 (figs. 117-118). Ninth

* Single individuals of *N. infimella* (H.-S.) cannot always be distinguished from *N. granella* (L.), but when several specimens are available there is usually no difficulty in distinguishing the species.

† The pinnacula are hardly visible in unstained specimens.

- abdominal segment with D1 and SD1 always on the same pinnaculum. Prolegs (figs. 138, 144) of segments three to six with ellipse of crochets always narrowly open on mesal side. Microscopic spines of abdomen (fig. 120) slender microtrichia. *Monopis* 20
19. Mandible (fig. 110) with distal seta more than half as long as proximal. Cosmopolitan *Trichophaga tapetzella* (Linnaeus)
 - Mandible (fig. 116) with distal seta very much less than half as long as proximal. Africa *Trichophaga swinhoei* (Butler)
20. SV group of eighth abdominal segment (fig. 134) unisetose; SV group of abdominal segments three to six (fig. 138) with SV2 more or less directly anterior to SV1. Prothorax (fig. 136) with SD1 separated from XD2 by only slightly more than the distance that separates XD1 from XD2. Nearly cosmopolitan *Monopis rusticella* (Clerck)
 - SV group of eighth abdominal segment (fig. 140) bisetose; SV group of abdominal segments three to six with SV2 always distinctly laterad from SV1, sometimes postero-laterad and sometimes antero-laterad (fig. 144). Prothorax (figs. 122, 143) with SD1 separated from XD2 by a distance equal to half again that which separates XD1 from XD2 21
21. Hypopharynx with slender cuticular processes but no large sclerotised plates on fleshy lobes. Cosmopolitan *Monopis ferruginella* (Hübner)
 - Hypopharynx with six or seven large sclerotised plates arranged longitudinally on each lobe (somewhat as in *M. rusticella*, fig. 126) in addition to the usual slender cuticular processes. New Hanover
Monopis congestella (Walker)
22. Prothorax (fig. 157) with distance between SD1 and XD2 twice as great as that between XD1 and XD2; L1 directly ventral to L2. First nine abdominal segments with SV setae minute. Cuticle of thorax and abdomen between pinnacula or sclerotised plates without microtrichia but with dense, more or less flat-topped, microscopic tubercles. Larva always in a flattened, fusiform case that has an opening flap at both ends 23
 - Prothorax (figs. 169, 178, 186) with distance between SD1 and XD2 much less than twice as great as that between XD2 and XD1; L1 between and below L3 and L2 so that it is postero-ventrad from L2. First nine abdominal segments with SV setae long and distinct. Cuticle of thorax and abdomen between pinnacula and sclerotised plates with dense, slender, microtrichia and without numerous more or less flat-topped tubercles. *Acedes* 24
23. Head with a convex ocellar lens on each side near anterior margin. Cosmopolitan *Tinea pellionella* (Linnaeus)
 - Head without convex ocellar lenses. Europe, North America
Tinea columbariella Wocke
24. Ninth abdominal segment (fig. 162) with D1, D2, SD1, and L1 of right and left sides on a single pinnaculum; eighth segment (fig. 162) with both D1 setae arising from a single pinnaculum and both D2 setae also arising from a single pinnaculum; eighth and ninth segments with V1 pinnaculum of right side fused to that of left side. Prolegs (fig. 163) of segments three to six each with 13-15 crochets. Pronotum very dark brown, nearly black. (Head with a lateral black stripe but sides between black stripe and cleavage lines not mottled. Tenth abdominal tergite dark brown. Coxae, femora and tibiae tinged with fuscus or dark brown.) Europe ... *Acedes ganomella* (Treitschke)
 - Ninth abdominal segment (fig. 174) with only D1 and SD1 on the same pinnaculum, D2 and L1 of each side being on separate pinnacula; eighth segment (fig. 174) with pinnaculae of D1 and D2 setae of right and left sides never fused; eighth and ninth segments with pinnacula of V1 setae separate. Prolegs of segments three to six each with more than 20 crochets. Pronotum moderately pale yellowish or red-brown 25

25. Head (fig. 172) on each side between the usual lateral black stripe and the cleavage line with numerous dark brown markings. Antenna (fig. 168) with mesoventral cone of apex of second segment as long or longer than third segment plus its seta. Head with Aa forming a straight line with A1 and A2. Mesothorax (fig. 173) with pinnaculæ of D1 plus D2 setae of right and left sides widely separated on dorsum. Abdomen with SD2 and SD1 of segments one to eight on the same pinnaculum. Prolegs of segments three to six with ellipse of crochets narrowly open on mesal side when proleg is evaginated. Tenth abdominal tergite moderately dark brown. Coxae, femora, and tibiae tinged with fuscous or dark brown. Europe
Acedes semifulvella (Haworth)
- Head on each side between the usual lateral black stripe and the cleavage line not mottled. Antenna (fig. 177) with mesoventral cone of apex of second segment much shorter than third segment plus its seta. Head with Aa between and considerably laterad from A1 and A2. Mesothorax (fig. 185) with pinnacula of D1 plus D2 setae of right and left sides joined across dorsum so that all D setae arise from a single pinnaculum. Abdomen with SD1 and SD2 of segments three to eight on separate pinnacula. Prolegs of segments three to six with ellipse of crochets closed on mesal side even when the proleg is fully evaginated. Tenth abdominal tergite usually white but at most very pale yellowish brown. Legs with sclerotised parts pale yellowish brown, not fuscous or dark brown 26
26. Prothorax (fig. 178) with XD1 more than twice as far from D1 as from XD2. First abdominal segment with SD1 and SD2 on the same pinnaculum. Mandible (fig. 175) distinctly narrowed apically. Europe, North America ...
Acedes pallescentella (Stainton)
- Prothorax (fig. 186) with XD1 only about $1\frac{1}{2}$ times as far from D1 as from XD2. First abdominal segment with SD1 and SD2 on separate pinnacula. Mandible (fig. 184) quadrate, not narrowed apically. Cosmopolitan
Acedes fuscipunctella (Haworth)
27. All legs (fig. 190) from femora to claw much shorter than coxal plate. Prothorax (fig. 190) with tergal and pleural plates fused so that D, XD, SD, and L setae of both right and left sides are on a single sclerotised plate; D1 nearly as close to XD1 as is XD2. Middle and hind coxae completely fused. North America *Eccritothrix trimaculella* (Chambers)
- All legs (figs. 199, 207) from femora to claw much longer than coxal plate. Prothorax (figs. 195, 203, 212) with tergal plate not fused to pleural so that D, XD, and SD setae are never on the same sclerotised plate as the L group; D1 three or more times as far from XD1 as is XD2 28
28. Front legs (fig. 199) with coxae very narrowly but nevertheless distinctly separated. Head (fig. 192) with Va antero-mesad from V3; Aa anterior to A2 and in a nearly straight line with A2 and A1. Meso- and metathorax (fig. 197) with D, SD, and L groups all on separate pinnacula; mesothorax (fig. 197) with L2 on a separate pinnaculum from that of L1 and L3; SV group of meso- and metathorax in a nearly horizontal line. (First eight abdominal segments (fig. 197) with L1 and L2 in a horizontal line with L1 well below the spiracle.) Tenerife, Nigeria
Praeacedes thecophora (Walsingham)
- Front legs (fig. 207) with coxae of right and left sides completely fused. Head (figs. 200, 210) with Va more or less directly mesad from V3; Aa far behind A2. Meso- and metathorax (figs. 204, 213) with D, SD, and L groups on the same sclerotised plate but sometimes with L2 of the metathorax on a separate pinnaculum although L2 of the mesothorax is never on a separate pinnaculum; SV group of meso- and metathorax in a nearly vertical line ... 29

29. Head (fig. 200) with P2 almost directly laterad from P1. Prothorax (fig. 203) with SD2 much nearer to D2 than it is to SD1; SD1 separated from XD2 by three times the distance that separates XD2 from XD1. Meso- and metathorax (fig. 204) with MD and MSD groups on separate pinnacula; D1 and D2 of both segments in a nearly horizontal line with D2 far in front of, and slightly dorsad from, D1; SD1 and SD2 of both segments in a nearly horizontal line with SD1 far in front of, and slightly dorsad from, SD2; metathorax with L2 on the same pinnaculum as L1 and L3. First eight abdominal segments with L1 and L2 in a strongly oblique line with L1 more or less directly behind spiracle. Middle and hind coxae narrowly separated. North Africa genus (?) species (?)
- Head (fig. 210) with P2 postero-laterad from P1. Prothorax (fig. 212) with SD2 much nearer to SD1 than it is to D2; SD1 separated from XD2 by twice or slightly less than twice the distance that separates XD2 from XD1. Meso- and metathorax (fig. 213) with MD1 on the same pinnaculum as the MSD group; D1 and D2 of both segments in an oblique line with D1 antero-dorsad from D2; SD1 and SD2 of both segments in a nearly vertical line with SD2 dorsad from SD1; metathorax with L2 not on the same pinnaculum as L1 and L3. First eight abdominal segments with L1 and L2 in a feebly oblique line with L1 behind and well below spiracle. Middle and hind coxae fused. *Phereoeca* 30
30. Metathorax with D2 about twice as far from SD2 as from D1. Brazil
Phereoeca uterella (Walsingham)
- Metathorax with D2 only about $1\frac{1}{2}$ times as far from SD2 as from D1 31
31. Canary Islands. Probably widely distributed in the Old World
Phereoeca allutella (Rebel)
- West Indies, Florida *Phereoeca walsinghami* (Busck)

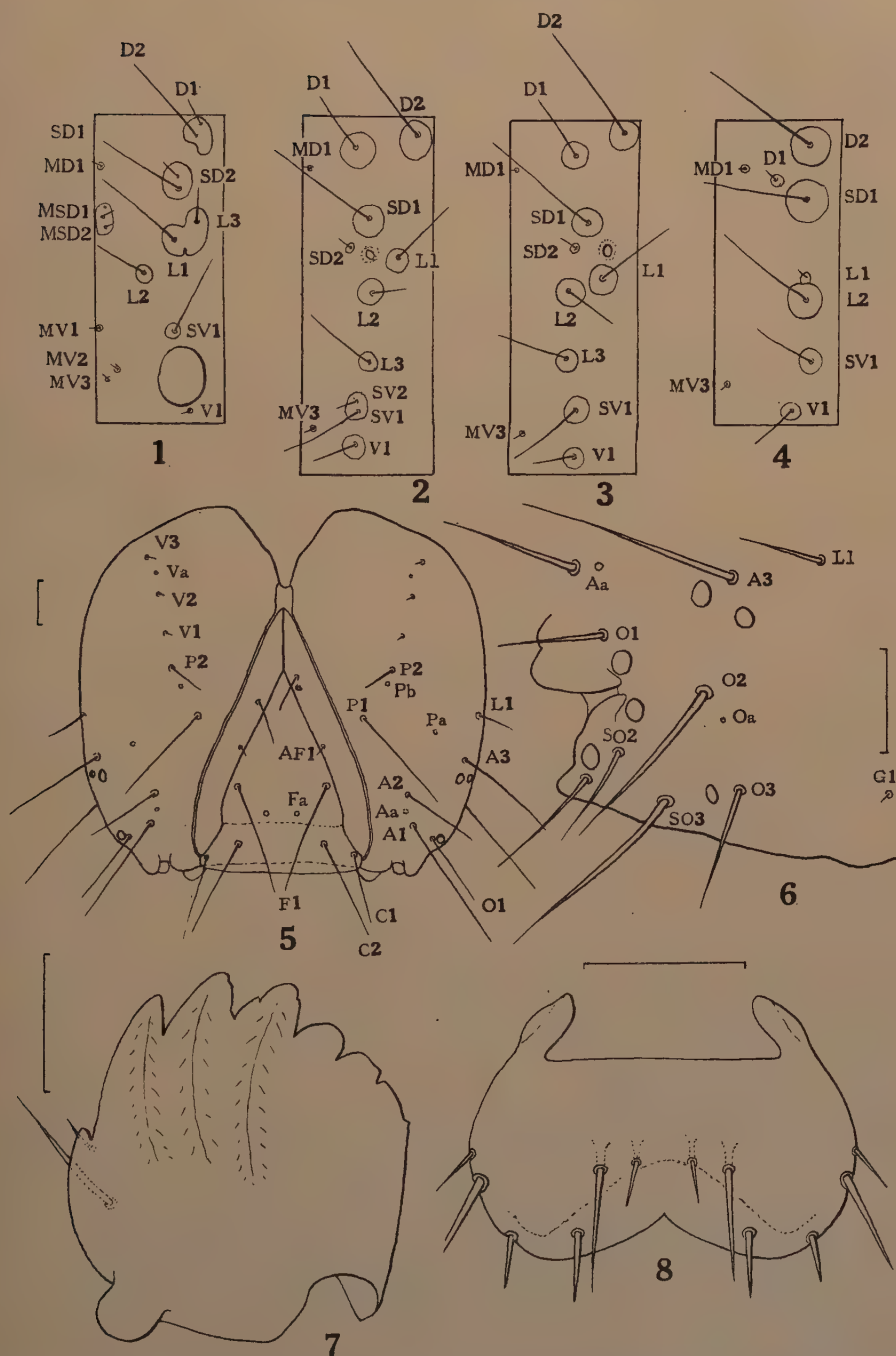
Scardia boleti (Fabricius) (1776) (figs. 1-14).

Mature larva. Length, 18-21 mm.; breadth, 3.2-4 mm.

Head pale reddish brown to dark brown; tergal plate of prothorax and dorsal surface of legs moderately dark brown; pinnacula and tergal plate of eighth abdominal segment paler brown; peritreme of spiracles pale brown to dark brown; cuticle elsewhere white or nearly white so that brown pinnacula contrast sharply with it; cuticle of abdomen with microtrichia as shown in fig. 13. Head (fig. 5) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending nearly two-thirds of distance to vertical triangle; six ocellar lenses on each side distributed as shown in fig. 6. Coxae of all legs widely separated; pinnacula of V1 setae distinctly separated from coxal plates; ventral prolegs with 25-30 crochets. Spiracles round or nearly round with those of eighth abdominal segment slightly smaller than those of prothorax but nearly a third larger than those of seventh abdominal segment. *Chaetotaxy.* AF1 (fig. 5) unusually short; AFa close to AF2, behind or before it and sometimes on adfrontal suture; AFa frequently absent on one or other side. L1 directly behind A3; La far from but nearly directly behind L1. Ga (not shown in fig. 6) behind and only slightly dorsal to G1. Prothorax (fig. 10) with first sensory pore indistinct; second and third pores large and in their usual position; L group of prothorax in all specimens only bisetose; SV group of prothorax in a nearly horizontal line. Chaetotaxy of metathorax like that of mesothorax (fig. 1). Chaetotaxy of abdomen as shown in figs. 2-4, 11, and 14.

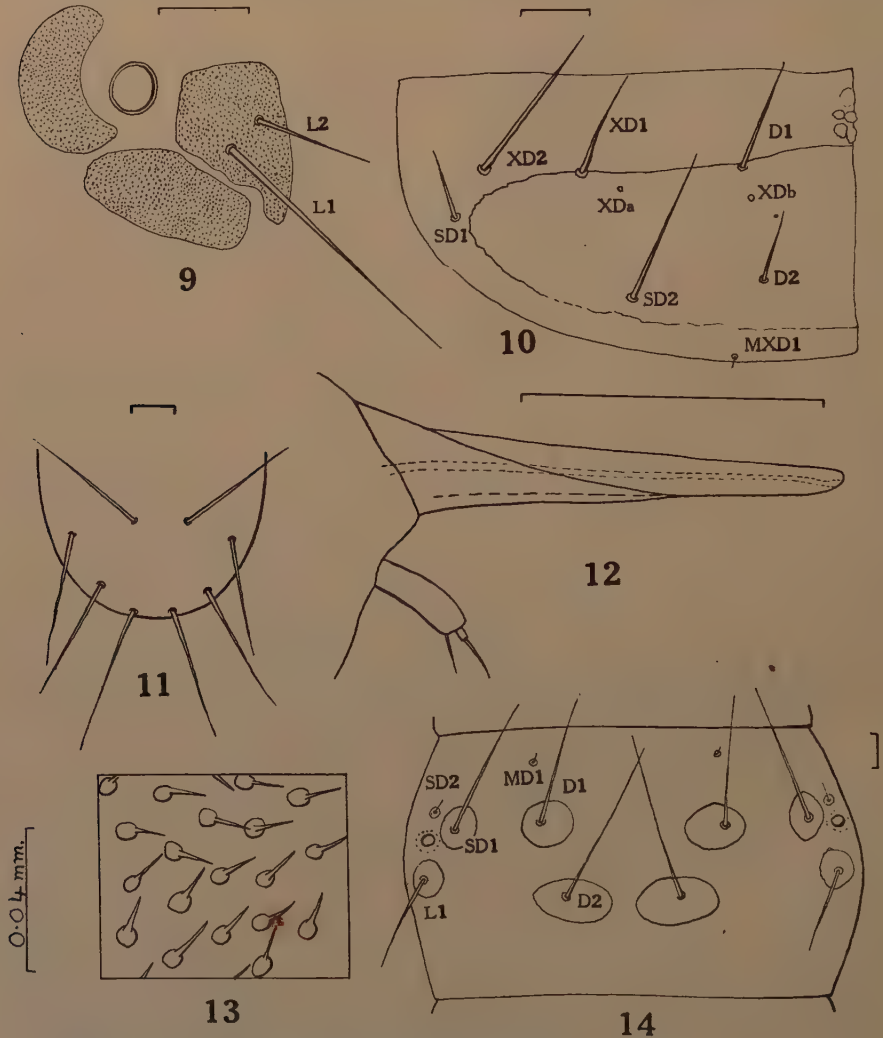
Distribution. Europe, Asia Minor.

Comparative notes. In all known larvae of the suborders Dacnonypha and Monotrysis the subprimary seta L3 of the prothorax is present from the second



Figs. 1-8.—*Scardia boleti* (F.), mature larva. (1) Mesothorax. (2) Seventh abdominal segment. (3) Eighth abdominal segment. (4) Ninth abdominal segment. (5) Dorsal view of head. (6) Left side of ocellar region of head. (7) Ventral view of right mandible. (8) Dorsal view of labrum.

instar. This seta is also present from the second instar in all but the specialised Ditrysia. Its absence in *Scardia* (it is said to be also absent in *Morophaga* H.-S.) is therefore most remarkable, and in all published keys this genus would run to the PYRALIDAE. Further unusual features of the genus are the wider separation of the D1 than the D2 setae on the first eight abdominal segments and the



Figs. 9-14.—*Scardia boleti* (F.), mature larva. (9) Spiracle and L group of right side of prothorax. (10) Dorsal view of left side of prothorax. (11) Dorsal view of tenth abdominal segment. (12) Left side of apex of prementum. (13) Microtrichia of seventh abdominal tergite. (14) Dorsal view of seventh abdominal segment.

absence of L3 (fig. 4) on the ninth abdominal segment. I have placed *Scardia*, *Morophaga*, and allied genera in a new subfamily, the SCARDIINAE (Hinton, 1955).

Habits. The larvae feed in fungi and in decayed wood attacked by fungi. My specimens were found mostly in *Polyporus sulfurella* near Pitton, Salisbury,

Wilts. Notes on the biology of a related species, *Scardia polypori* (Esp.) (= *boletella* (F.)), are given by Mitterberger (1911), and notes on the biology of *Morophaga morella* (Dup.) are given by Dumont (1930).

***Lindera tessellatella* Blanchard (1852) (figs. 15-31).**

Mature larva. Length, 24-28 mm.; breadth, 3-4 mm.

Head reddish brown to dark brown; tergal and pleural plates of prothorax and dorsal surface of legs yellowish brown; tergal plate of tenth abdominal segment paler yellowish brown; some specimens with pinnacula of mesothorax pale yellowish but most specimens with these and all pinnacula of mesothorax and abdomen very indistinct; peritreme of spiracles black or nearly so; cuticle elsewhere white or nearly white; cuticle of abdomen with minute microtrichia as in *Scardia* (fig. 13). Head (fig. 26) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending half of distance to vertical triangle; without ocellar lenses but sometimes with a few distinct ocellar pigment spots below a pale area of cuticle in usual position of fourth ocellus; surface densely, microscopically reticulate. Coxae of all legs widely separated; pinnacula of V1 setae fused to coxal plates. Ventral prolegs with 38-45 crochets; above each proleg with a moderately broad band of minute recurved spines (somewhat like minute crochets) which are slightly larger and more numerous on anterior than on posterior sides. Prolegs of tenth abdominal segment without minute recurved spines above crochets. Spiracles broadly oval with vertical diameter greatest; spiracles of eighth abdominal segment twice as large as those of seventh and very nearly as large as those of prothorax. *Chaetotaxy.* Dorsal surface of cranium as shown in fig. 26; Ga and G1 close together and in a nearly vertical line; SO setae forming a nearly equilateral triangle; Oa behind and slightly ventrad from O2 and much nearer to latter than to O3. Chaetotaxy of prothorax as shown (figs. 28-29); SV setae in a nearly horizontal line. Chaetotaxy of meta-thorax like that of mesothorax (fig. 22) and both segments with pinnaculum of L2 narrowly separated from that of L1 + L3. Chaetotaxy of abdomen as shown in figs. 23-25, 30-31; SV group of 1-6 trisetose and 7-9 bisetose.

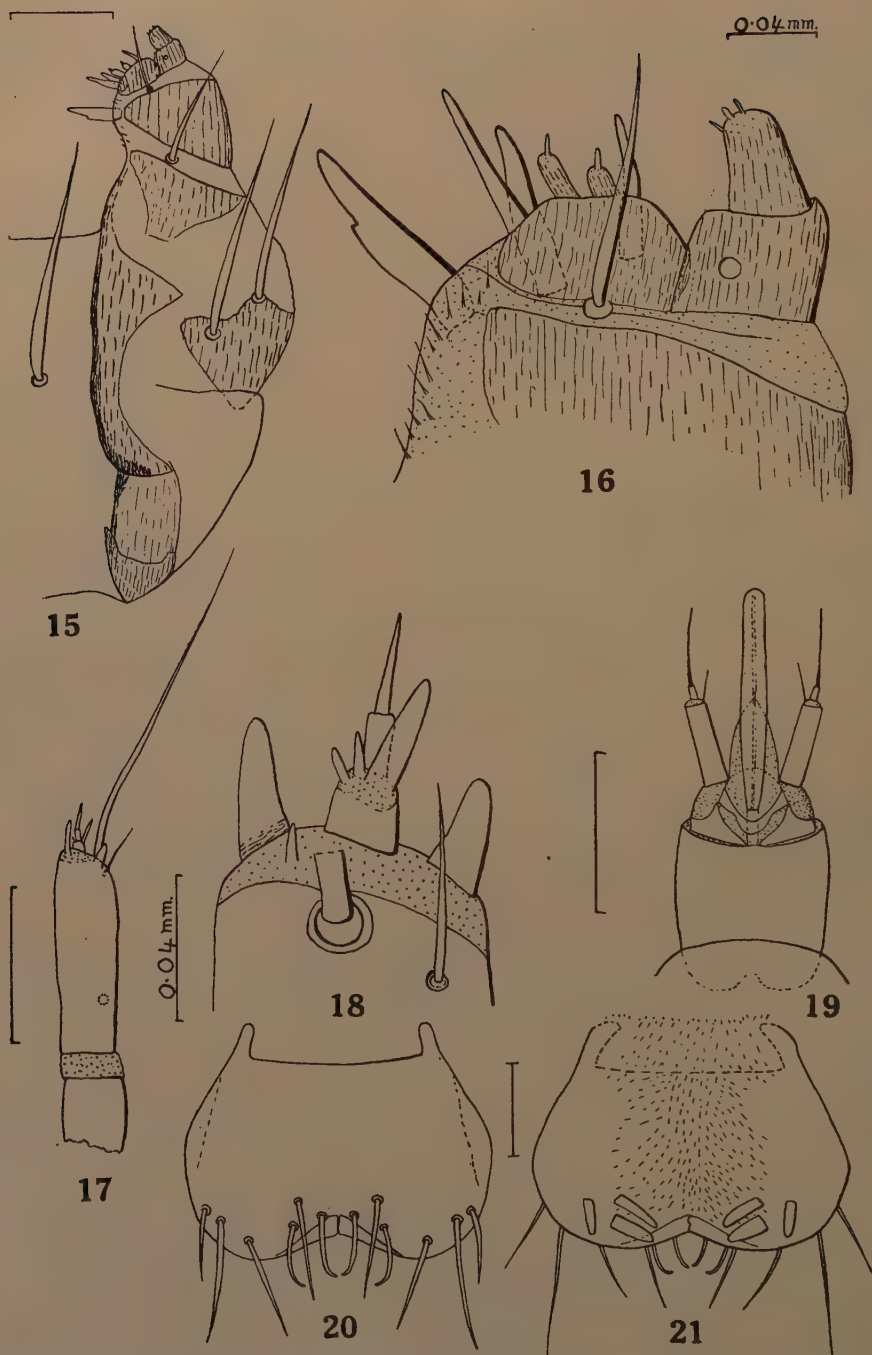
Distribution. South America, California, Australia, New Zealand, Fiji Islands, Britain.

Comparative notes. This (and *Setomorpha*?) is the only species of NEMAPOGONINAE known to occur in stored products that is without convex ocellar lenses and the only species with minute recurved spines above the ventral prolegs. The black or nearly black peritreme of the spiracles and the large size of the mature larvae are additional distinguishing features. The description is based on specimens bred by me.

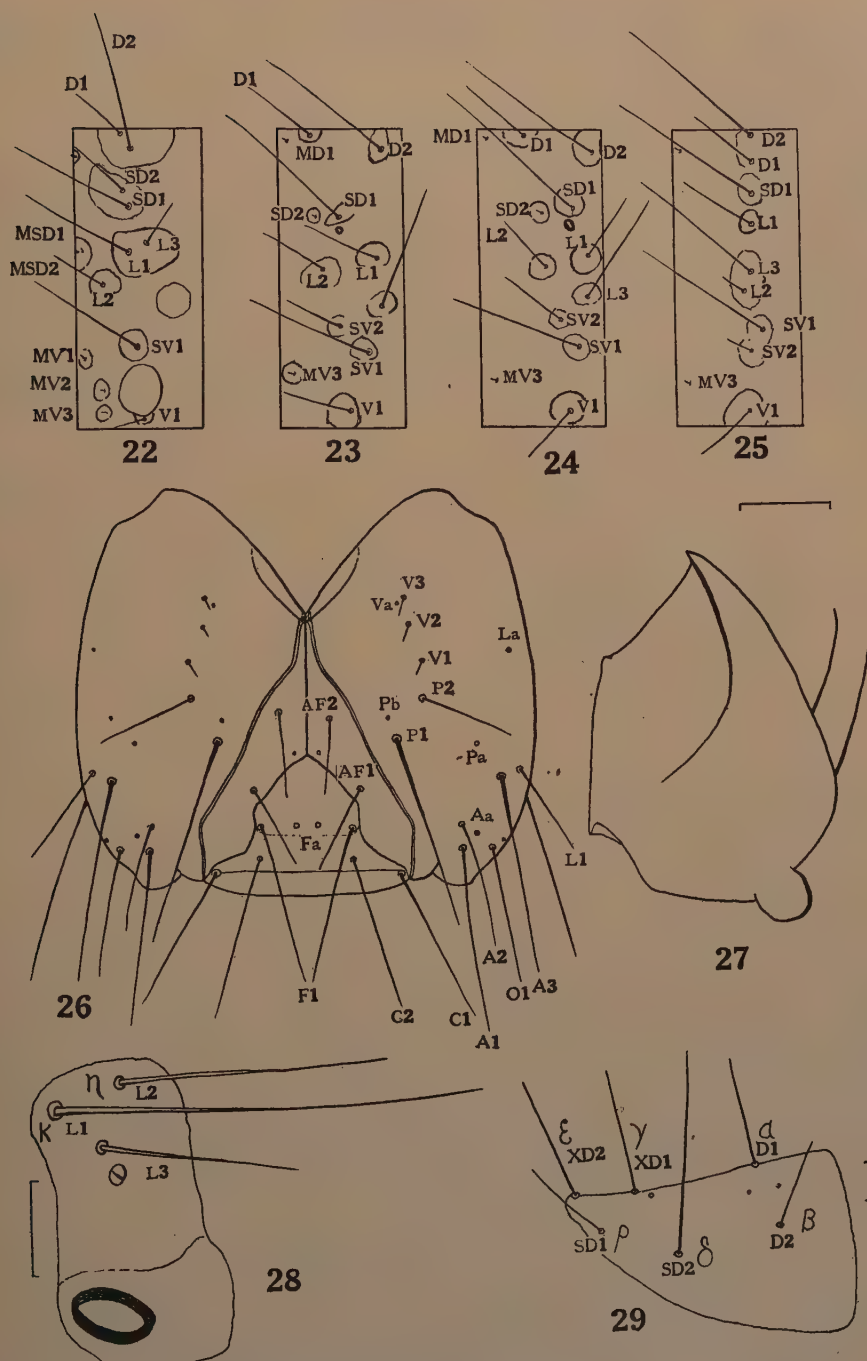
Habits. It was first found in England in 1943 in a mill at Bootle, breeding in refuse on the floor (Stringer, 1943). In the gut of a mature larva dissected there were numerous Tyroglyphid mites and the remains of lepidopterous larvae, including the mandibles of smaller *Lindera* larvae.

***Setomorpha rutella* Zeller (1852).**

Two larvae of this species have been given to me by the authorities of the U.S. National Museum. Although only rather poor descriptions of the larva exist in the literature, the specimens sent to me agree in all particulars with such descriptions, and I have, therefore, no reason to dispute their identity. I am unable to distinguish these larvae in any particular from those of *Lindera tessellatella* Blanch. which I have bred myself. I am therefore forced to conclude that *Setomorpha* and *Lindera* are synonymous. *S. rutella* and *L.*



Figs. 15-21.—*Lindera tessellatella* Blanchard, mature larva. (15) Ventral view of left maxilla. (16) Ventral view of apex of left maxilla. (17) Dorsal view of right antenna. (18) Ventral view of apex of right antenna. (19) Ventral view of prementum. (20) Dorsal view of labrum. (21) Ventral view of same.

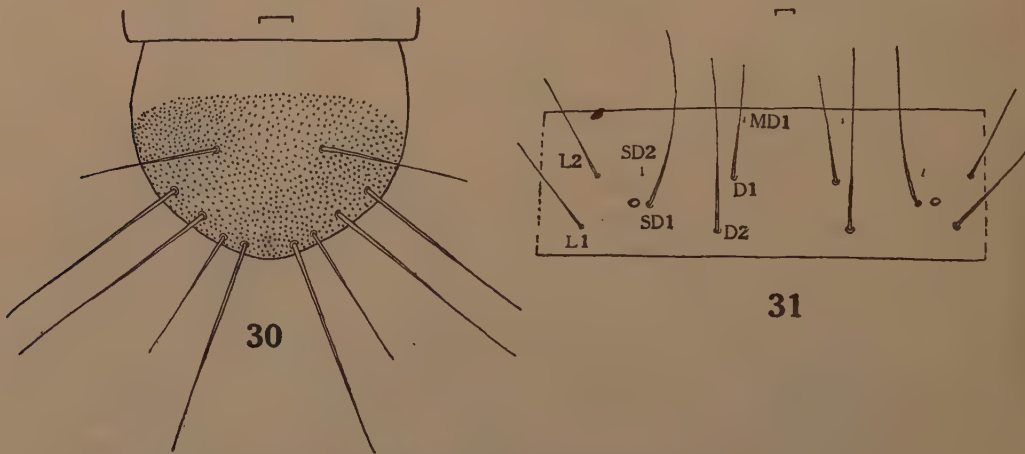


Figs. 22-29.—*Lindera tessellatella* Blanchard, mature larva. (22) Mesothorax. (23) Seventh abdominal segment. (24) Eighth abdominal segment. (25) Ninth abdominal segment. (26) Dorsal view of head. (27) Ventral view of left mandible. (28) Spiracle and L group of prothorax. (29) Dorsal view of left side of prothorax.

tessellatella are, however, not conspecific, and the two species may easily be distinguished in the adult stage by the structures of the male genitalia (e.g. Corbet & Tams, 1943a).

Distribution. Cosmopolitan.

Habits. It is an important pest of dried tobacco leaves in the East Indies (e.g. Diakonoff, 1938; Jensen, 1917; Keuchenius, 1917), where it is also frequently found in stored cacao or cacao seeds (Roepke, 1918; Ultée, 1931). An extensive list of records from the literature of its occurrence in stored tobacco and other commodities in the East Indies is given by Diakonoff (1938). It has also been found in stored tobacco elsewhere, e.g. India (Lefroy, 1909; Fletcher, 1920) and the Soviet Union (Shelyuzhko, 1935). In Africa it has been found in a wide variety of animal and vegetable materials: in muscle fibres on skull of hippopotamus (Walsingham, 1908); in Uganda in bulbs from the Seychelles (Hargreaves, 1927); in maize (Morstatt, 1913) and cotton seed (Morstatt, 1914) in



Figs. 30-31.—*Lindera tessellatella* Blanchard, mature larva. (30) Dorsal view of tenth abdominal segment. (31) Same of eighth abdominal segment.

East Africa; and in Tanganyika in coffee seed from the Belgian Congo (Ritchie, 1935). It has been found in Brazil nuts in Malaya (Gater, 1925), in stored coriander seed, grain, wheat flour, beans and *Dolichos biflorus* (seeds?) in India (Fletcher, 1920) and in a *Polistes* nest in Puerto Rico (Forbes, 1933). A number of original records of its occurrence in Java are cited by Diakonoff (1938): in bee's nest, on bird skins, in bird excrement, on white onions, on hyacinth and other bulbs imported from the Netherlands, and in galls of *Uromicladium tepperianum* on *Albizia montana*.

Notes on its life-history have been given by a number of writers, especially Fletcher (1920), Jensen (1921), and Keuchenius (1917). The eggs are deposited singly or in groups, and they are glued to the substrate. As many as 143 eggs may be laid by a single female. The duration of the various stages has not been adequately described under controlled temperatures or humidities, to say nothing of nutrition, and there therefore seems to be little point in citing here such figures as are available. The larva pupates in a closely woven and smooth cocoon within a loosely spun outer framework or outer cocoon, to which particles of food and excrement adhere. The inner cocoon is similar to that of *Lindera tessellatella* Blanch.

Haplotinea ditella (Pierce & Metcalfe) (1938) (figs. 32-46).

Mature larva. Length, 12-14 mm.; breadth, 2 mm.

Head moderately pale brown to dark brown; tergal and pleural plates of prothorax, tergal plate of ninth abdominal segment, and most of legs moderately pale yellowish brown; peritreme of spiracles as pale brown as setae; cuticle elsewhere white with pinnacula only clearly distinguishable in stained specimens; cuticle of abdomen with dense microtrichia. Head (fig. 32) with part of frontoclypeal apotome enclosed by adfrontal sutures extending half of distance to vertical triangle; usually with two distinct ocellar lenses, the most anterior being fifth ocellus and that above and behind it possibly either first or second ocellus; posterior ocellar lens often much smaller than anterior and sometimes indistinct or absent; surface of cranium densely, microscopically reticulate and with numerous irregularly distributed, oval or quadrate callosities often two to four times as broad as sockets of larger cranial setae. Coxae of all legs widely separated; pinnacula of V1 setae separated from coxae by at least half a diameter of a pinnaculum. Ventral prolegs with 23-25 crochets. Spiracles circular or nearly circular; spiracles of eighth abdominal segment nearly twice as large as those of seventh (1.8:1) and equal in size to those of prothorax. *Chaetotaxy.* Cranium as shown in figs. 32-33. Prothorax as shown in figs. 36 and 44; SV setae in a nearly horizontal line and on the same pinnaculum. Chaetotaxy of metathorax like that of mesothorax (fig. 40). Chaetotaxy of abdomen as shown in figs. 41-43 and 45-46; SV group of 1-6 trisetose and of 7-9 bisetose.

Earlier instars. The posterior ocellus is more frequently indistinct or absent than in the final instar.

Distribution. Britain, Holland, Austria, Germany. Probably much more widely distributed.

Comparative notes. The presence of one or two ocellar lenses on each side of the head will serve to distinguish it from all other NEMAPOGONINAE found in stored products except *Haplotinea insectella* (F.). It resembles *Lindera* (and *Setomorpha*?) from which, in addition to its much smaller size, it may be distinguished as shown in the key. The larvae on which this description is based were bred at the Pest Infestation Laboratory of the D.S.I.R. at Slough. I have also examined larvae collected in flour mills in Scotland and England.

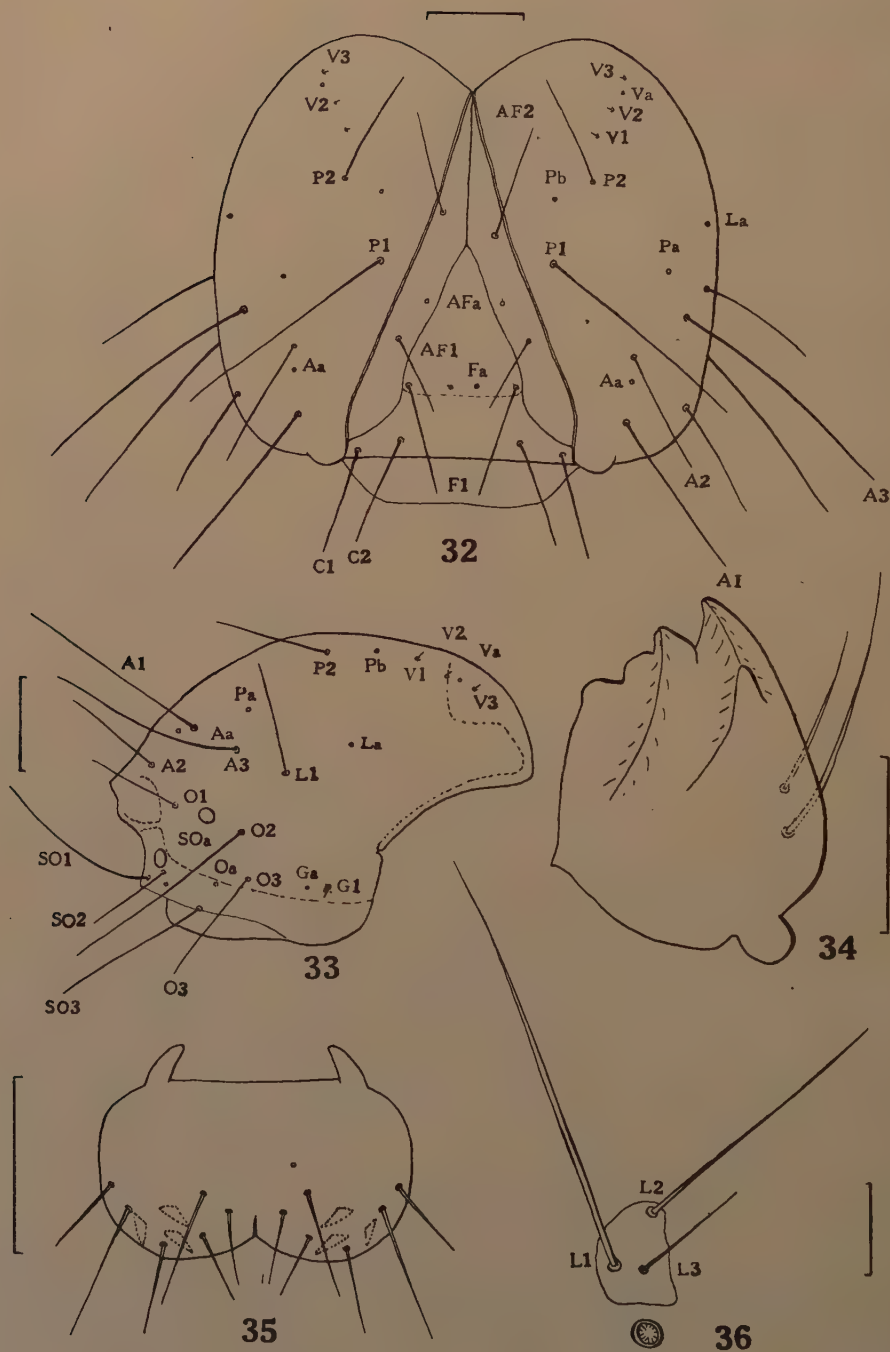
Habits. It has been found in England in mills, warehouses, and granaries on a variety of stored vegetable products, especially cereals (*e.g.* Howe, 1940). Records of its occurrence in England during the years 1950-1954 are as follows: in flour mills in London, Bishops Stortford, Herts., and Newbury, Berks.; in provender mills in London and Stockport, Lancs.; in sievings of home-grown barley at Thruxton, Hants.; in a grain silo in London; in a bakery in Southampton; in wharfs in London on Chinese groundnuts and in grain, rice, and flour stores; in flour spillings and Canadian flour in a buffer depot at Wooburn Green, Bucks.; in a grain store at South Leigh, Oxon.; and in Canadian wheat and flour in a ship at Bristol.

Haplotinea insectella (Fabricius) (1794).

Mature larva.

Externally similar to that of *Haplotinea ditella* (Pierce & Metcalfe) but with SV1 and SV2 of eighth abdominal segment on same pinnaculum instead of on separate pinnacula. Head apparently without a posterior ocellar lens.

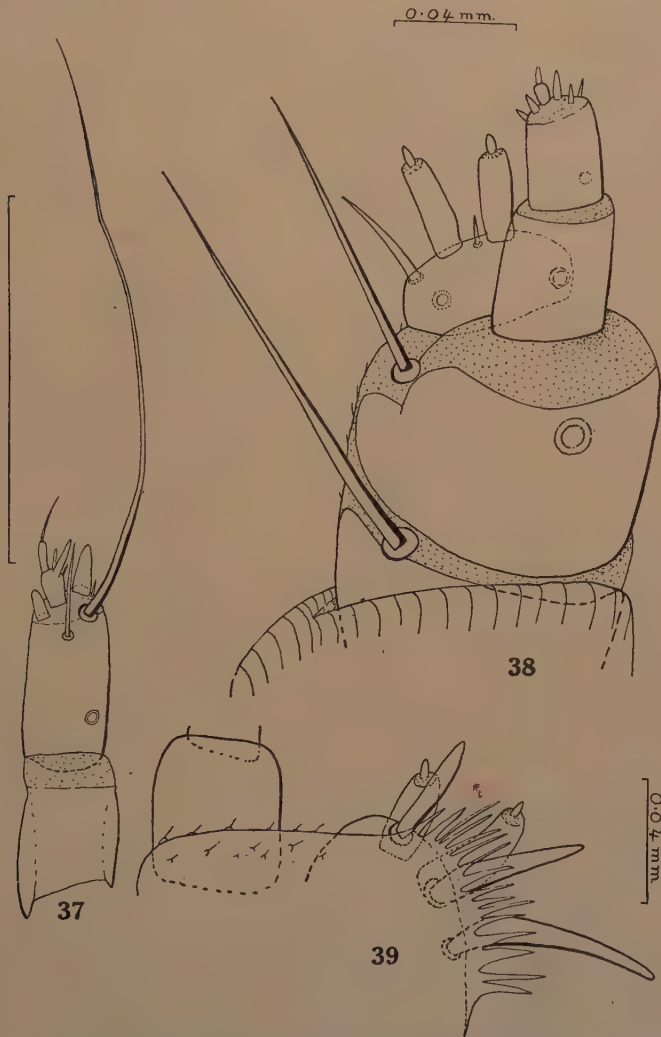
I have been able to examine only 10 larvae of *H. insectella*. These were found in the decayed woodwork of a barn at Linton, Cambs. in 1943. All adults that emerged from the wood over a considerable period were *H. insectella*, and I therefore have little doubt that my identification is correct. It can hardly be



Figs. 32-36.—*Haplotinea ditella* (Pierce & Metcalfe), mature larva. (32) Dorsal view of head. (33) Left side of head. (34) Ventral view of left mandible. (35) Dorsal view of labrum. (36) Spiracle and L group of prothorax.

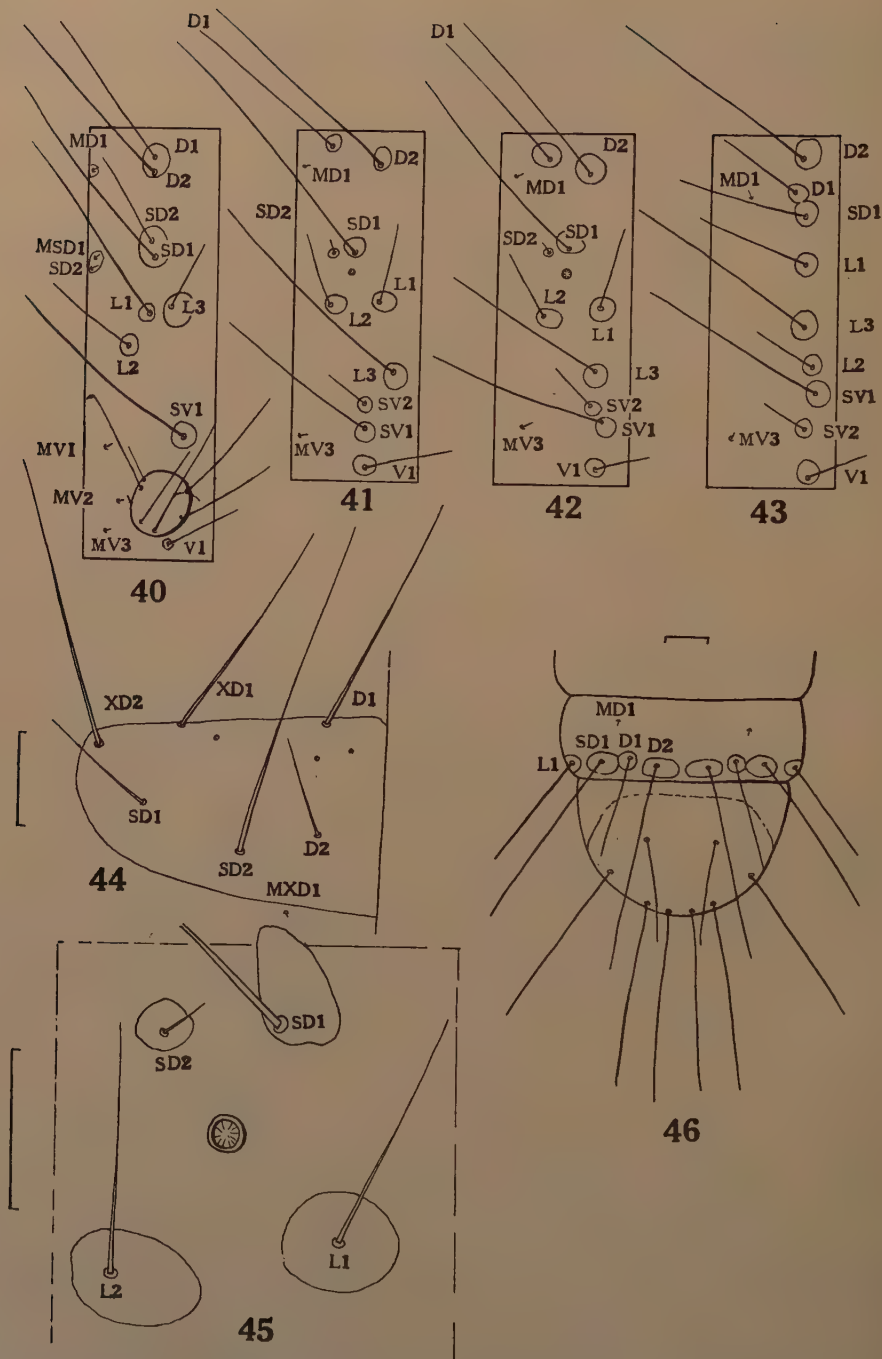
expected that the SV setae of the eighth abdominal segment will arise on the same pinnaculum in all specimens of *H. insectella*, and for this reason the differences cited here between the two species are inadequate.

Distribution. Europe, Asia.



Figs. 37-39.—*Haplotinea ditella* (Pierce & Metcalfe), mature larva. (37) Ventral view of left antenna. (38) Ventral view of left maxilla. (39) Dorsal view of apex of maxillary lobe.

Habits. Since *H. ditella* and *H. insectella* were only distinguished in 1938, it is likely that some of the earlier records of the habits of *H. insectella* refer in fact to *H. ditella*. It has been found in granaries (Barrett, 1887b; Bower, 1898; Howe, 1940), in barns and stables (Barrett, 1878; Ford, 1931; Tutt, 1892; Wilkinson, 1898), in houses (Farren, 1886; Waters, 1928), in fungus on walls in cellars and vaults (Kane, 1900). It is also found out-of-doors about fungus-infested trunks and stumps of various kinds, and it is probable that it sometimes breeds in fungi, as suggested by Barrett (1872). Records of its occurrence in



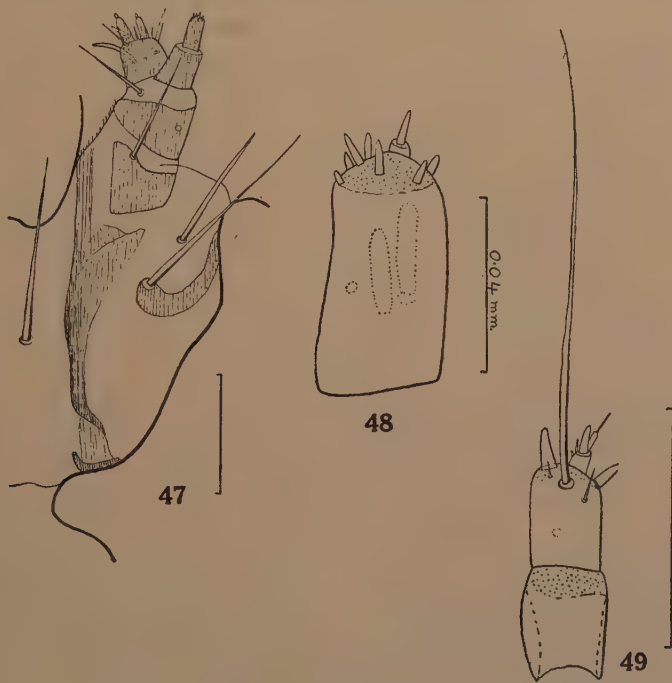
Figs. 40-46.—*Haplotinea ditella* (Pierce & Metcalfe), mature larva. (40) Mesothorax. (41) Seventh abdominal segment. (42) Eighth abdominal segment. (43) Ninth abdominal segment. (44) Dorsal view of left side of prothoracic plate. (45) Spiracle and associated setae of left side of eighth abdominal segment. (46) Dorsal view of ninth and tenth abdominal segments.
 Note: Fig. 40. MSD2 is shown as SD2 in error.

Britain during the years 1949-1952 are as follows: in flour mills in London and Glasgow; in soya flour at a wharf in London; and on Canadian wheat at a wharf in Southampton.

Nemapogon parasitella (Hübner) (1796) (figs. 47-62).

Mature larva. Length, 12-14 mm.; breadth, 1.7-2.0 mm.

Head moderately dark brown or reddish brown with anterior margin, hind margin, parts of postgenae, and sometimes adfrontal areas black or nearly black; tergal plates of prothorax usually about as dark brown as head but less reddish; pinnacula very distinct, moderately pale brown; tergal plate of tenth abdominal segment usually slightly darker than pinnacula; legs pale yellowish brown; peritreme of spiracles brown; cuticle elsewhere white or nearly white and densely clothed with microtrichia. Head (fig. 50) with part of fronto-clypeal

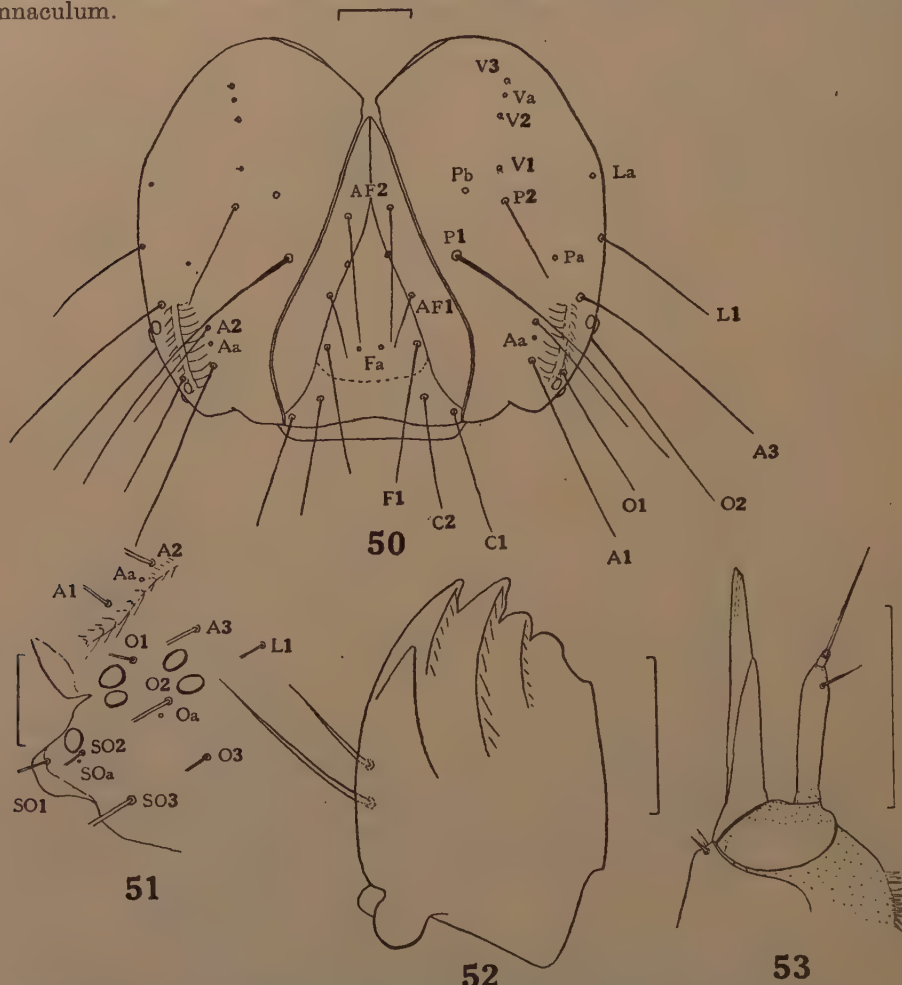


Figs. 47-49.—*Nemapogon parasitella* (Hübner), mature larva.
(47) Ventral view of left maxilla. (48) Ventral view of apex of left maxillary palp. (49) Right antenna.

apotome enclosed by adfrontal sutures extending two-thirds of distance to vertical triangle; each side with only five convex ocellar lenses, as shown in fig. 51; with a slight ridge above ocelli, as shown in fig. 50; surface of head with microscopic reticulation dense but not very distinct and with fine, irregularly distributed, transverse rugae. Coxae of all legs widely separated; pinnacula of V1 setae separated by one-third to about one-half of their diameters from coxae. Ventral prolegs with 27-31 crochets. Spiracles circular or broadly oval; spiracles of eighth abdominal segment about one-fourth larger than those of seventh (21:15) and about two-thirds as large as those of prothorax.

Chaetotaxy. Head (figs. 50-51) with AFa more or less on adfrontal suture and therefore difficult to see. Prothorax (figs. 58-59) with posterior seta of L group largest and therefore possibly L1; seta in normal position of L1 nearly as large

as posterior member of group and therefore possibly L1, in which case largest and most posterior seta is L3 and not L1. Setae of metathorax like those of mesothorax (fig. 54). Chaetotaxy of abdomen as shown in figs. 55-57 and 62; D and SD setae of each side of ninth segment apparently always on same pinnaculum.

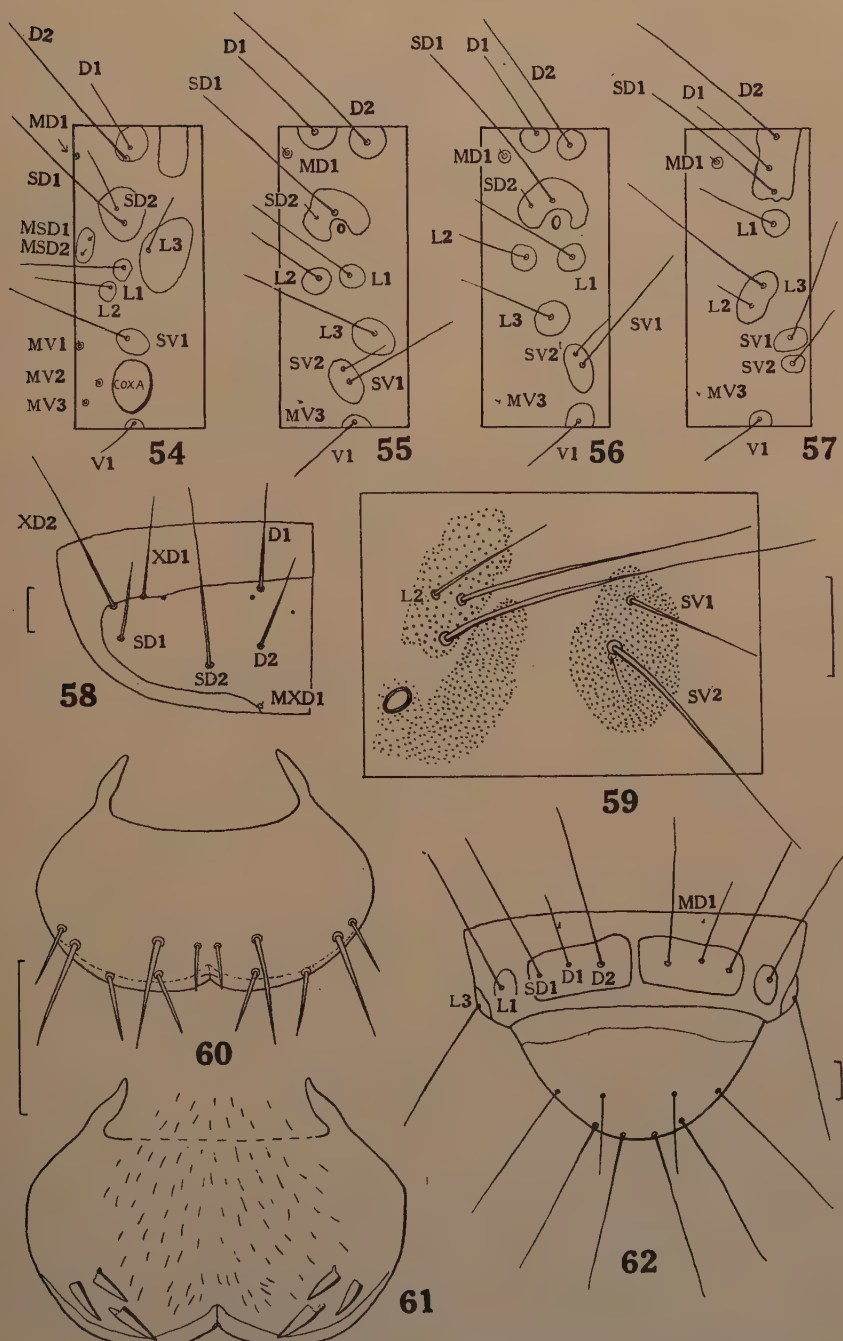


Figs. 50-53.—*Nemapogon parasitella* (Hübner), mature larva. (50) Dorsal view of head. (51) Ocellar region of left side of head. (52) Ventral view of right mandible. (53) Apex of left side of prementum.

Distribution. Europe.

Comparative notes. Of the species known to me this is close only to *N. fulvimitrella* (Sodoffsky) from which it may be distinguished as shown under the heading of that species.

Habits. Large numbers of larvae have been taken by me feeding in *Polystictus*, *Polyporus*, and other fungi in Linton, Cambs., and Ashted, Surrey. It has been found on *Polyporus* on beech (Morley, 1935), on a dry woody fungus (Wakely, 1935), and in fungi on beech, willow, and pine (Schütze, 1931). It has been bred from an old gate post (Carr, 1939), and adults have been found on an old beech log (South, 1918).



Figs. 54-62.—*Nemapogon parasitella* (Hübner), mature larva. (54) Mesothorax. (55) Seventh abdominal segment. (56) Eighth abdominal segment. (57) Ninth abdominal segment. (58) Dorsal view of left side of prothorax. (59) Spiracle and L and SV groups of right side of prothorax. (60) Dorsal view of labrum. (61) Ventral view of same. (62) Dorsal view of ninth and tenth abdominal segments.

The following parasites have been recorded from it: *Apanteles* sp. (Schütze & Roman, 1931), *A. hoplites* (Ratz.) (Falcoz, 1925), *Agathis calculator* (F.) (referred to as *Microdus calculator* (F.)) (Morley & Rait-Smith, 1933), and *Lissonota variabilis* Holmgr. (Schütze & Roman, 1931).

***Nemapogon fulvimitrella* (Sodoffsky) (1830) (fig. 63).**

Mature larva.

Similar in size and appearance to *N. parasitella* (Hübner) and apparently externally identical to it except that on ninth abdominal segment (fig. 63) D2 is not on the same pinnaculum as D1 and SD1.

Of 74 larvae examined, including all instars except the first, only one final-instar larva had the pinnaculum of D2 partly fused to that of D1 + SD1.

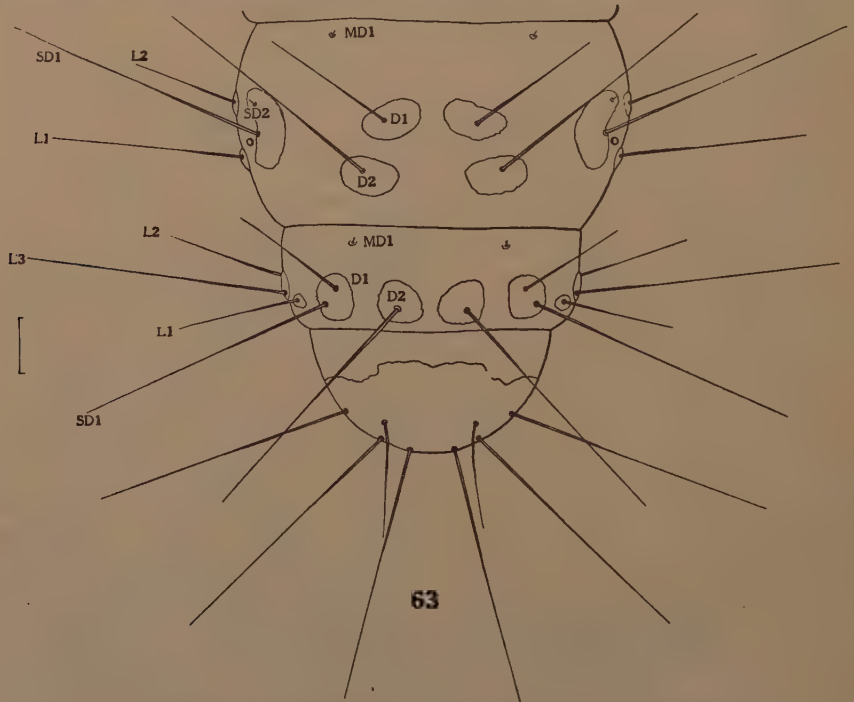


Fig. 63.—*Nemapogon fulvimitrella* (Sodoffsky). Dorsal view of eighth, ninth, and tenth abdominal segments of mature larva.

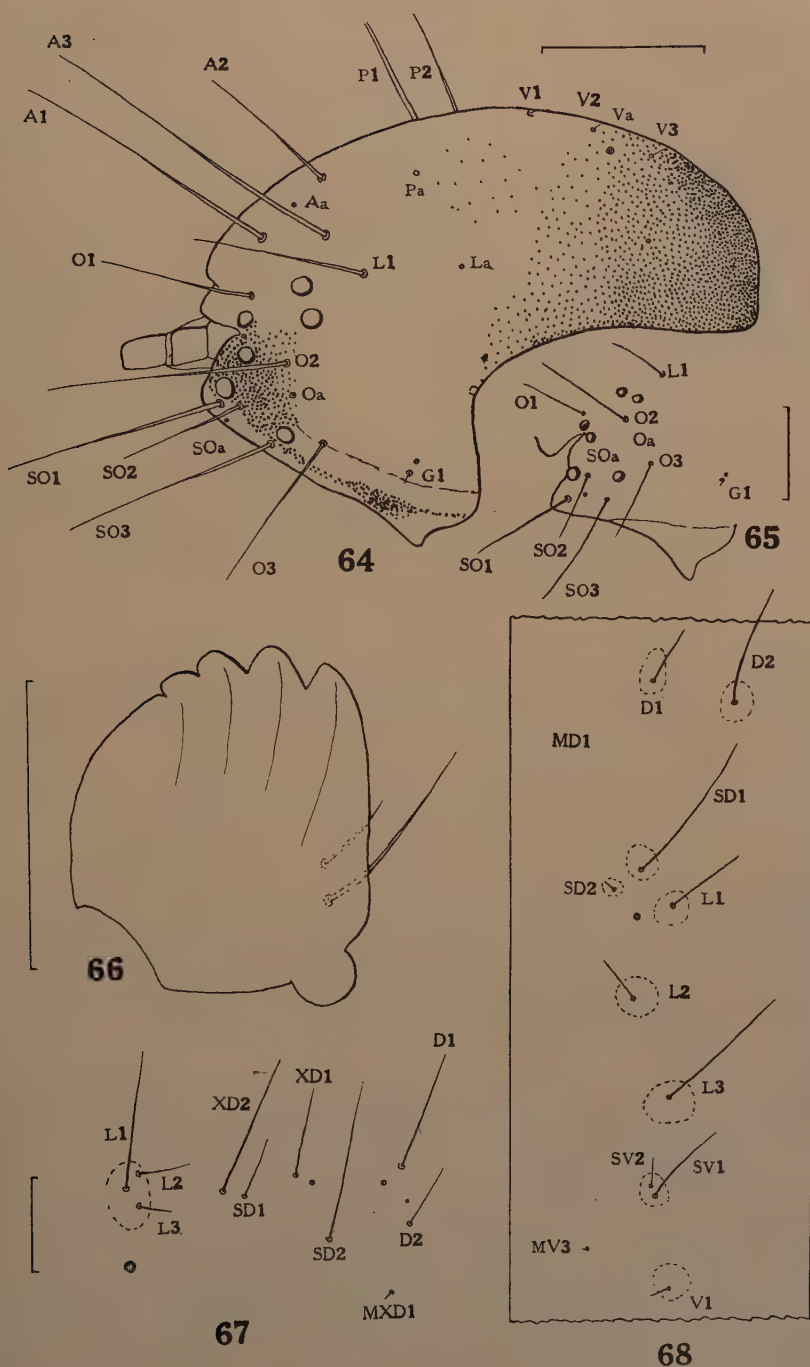
Distribution. Europe.

Habits. Over 100 larvae were taken by me at various times from *Polyporus* growing on fallen beech trees or on decaying beech trunks near Pitton, Salisbury, Wilts. Some of the larvae were found boring in the rotten wood near the *Polyporus*. Some published records of its habits are: in fungi and rotten wood (Spuler, 1910), in fungus-infested birch (Barrett, 1887a), bred from *Polyporus radiatus* (Fryer, 1930), *Polyporus* on beech tree (Morley, 1935), adult common on tree trunks (Carr, 1939), and apparently prefers oak and beech trunks (Sich, 1909a).

***Nemapogon ruricolella* (Stainton) (1849) (figs. 64–68).**

Mature larva. Length, 6.5–7.5 mm.; breadth, 1.5 mm.

Head moderately pale to moderately dark yellowish brown with darker, sometimes nearly black, areas as shown in fig. 64; fronto-clypeal apotome usually



Figs. 64-68.—*Nemapogon ruricolella* (Staint.), mature larva. (64) Left side of head. (65) Ocular region of left side, somewhat flattened. (66) Ventral view of left mandible. (67) Dorsal and lateral setae of left side of prothorax. (68) Seventh abdominal segment.

distinctly darker than adjoining areas of cranium; tergal plates of prothorax and dorsal surface of legs pale yellowish brown; peritreme of spiracles pale brown, indistinct; cuticle elsewhere white or nearly white with pinnacula not visible (mag. $\times 75$) without staining; surface of cuticle with dense microtrichia. Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending slightly more than three-fourths of distance to vertical triangle; each side with six convex ocellar lenses, as shown in fig. 64; with a feebly impressed (mag. $\times 75$) reticulate microsculpture and indistinctly, sparsely, and irregularly rugose. Coxae of all legs widely separated; pinnacula of V1 setae fused to coxae. Ventral prolegs with 19-20 crochets but sometimes with 17 or as many as 22. Spiracles circular; spiracles of eighth abdominal segment about a fourth larger than those of seventh and about four-fifths as large as those of prothorax. *Chaetotaxy*. AF1 and AF2 slightly less widely separated than AF1 and F1; AFa in a straight line and half way between AF1 and AF2. V group nearly equally separated from each other, and Va distinctly laterad from V2. P2 obliquely laterad from P1, as in *N. granella* (fig. 72), and Pa only slightly laterad from P1; other cranial setae as shown in fig. 64. Prothorax (fig. 67) with SD1 twice as far from XD1 as from XD2; SV setae in a nearly horizontal line and on the same pinnaculum. Mesothorax with chaetotaxy as in *N. granella* (fig. 79) and meta-thorax setose like mesothorax. Abdomen with chaetotaxy of first eight segments like that of seventh (fig. 68) except that on segments 2-6 SV3 is present; ninth segment setose like that of *N. granella* (fig. 82).

Distribution. England.

Comparative notes. The fact that SD1 of the prothorax is twice as far from XD1 as from XD2 will serve to distinguish it immediately from the species closely related to it, i.e., *N. emortuella* (Zell.), *N. cloacella* (Haw.), *N. granella* (L.), and *N. infimella* (H.-S.).

Habits. It breeds in fungus (Bankes, 1897). The 43 larvae on which the description is based were bred by me in *Polyporus*.

***Nemapogon emortuella* (Zeller) (1839) (fig. 69).**

Mature larva. Length, 6.5 mm.; breadth, 1.4 mm. Externally identical to *N. ruricolella* (Staint.) but with SD1 of prothorax equidistant between XD1 and XD2. In all specimens available (1 mature larva, 1 2nd instar, 2 shed cuticles of final instar) the tergal plates of the prothorax are moderately dark brown instead of pale yellowish brown as in *N. ruricolella*.

Distribution. Europe.

Habits. It has been found on fungi growing on beech, hornbeam, oak, willow, and alder (Schütze, 1931). My specimens were found on *Polystictus* on beech logs near Pitton, Salisbury, Wilts.

***Nemapogon cloacella* (Haworth) (1828) (figs. 70-71).**

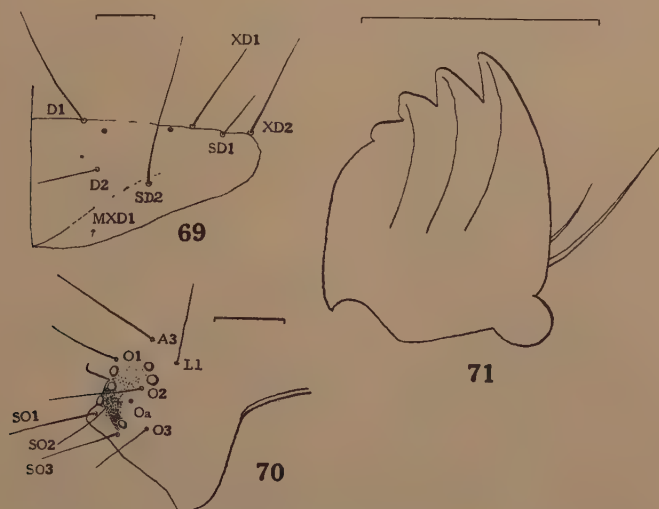
Mature larva. Length, 7 mm.; breadth, 1.5 mm.

Similar to other members of *N. granella* group. Its chief distinguishing features are: Head with posterior region not darker or only with extreme posterior margin darker; fuscous eye-spot (fig. 70) extending posteriorly to first two ocelli. AF1 much nearer to AF2 than to F1; AFa half way between AF setae; AF1 slightly in front of P1 level; V setae equally separated with Va nearly three times as far from V2 as from V1; Aa in a line with, and half way between, A1 and A2; L1 separated from second ocellus by two diameters of the ocellus; Ga above and slightly behind G1; other cranial setae as shown in fig. 70.

Prothorax with SD1 slightly nearer to XD2 than to XD1. Meso- and metathorax and abdomen with setae as shown for *N. granella* (figs. 79-85, 88). Pinnacula of thorax and abdomen very distinct when stained.

Distribution. Cosmopolitan? Most of the records of its occurrence outside Europe and the Mediterranean littoral require confirmation, as in the past a number of very closely related species have been confounded with it.

Habits. In Europe it has been bred from *Polyporus radiatus* (Fryer, 1930), from a dry woody fungus (Wakely, 1935), and larvae have been found in rotten wood and unidentified fungi of various kinds (Barrett, 1887a; Schütze, 1931; Waters, 1928). In the United States it has been found in *Polyporus sulphureus* and *P. tsugae* (Weiss, 1919). In Europe, the adults are often taken about fungi on tree trunks (Morley, 1935; Sich, 1908, 1909a, 1909b; Spuler, 1910), and it



Figs. 69-71.—(69) *Nemapogon emortuella* (Zell.), setae of right side of prothorax of mature larva. (70) *N. cloacella* (Haw.), ocellar region of left side of head of mature larva. (71) Ventral view of right mandible of same.

has been found in numbers on the cork oak (*Quercus suber*) in Algeria (Chrétien, 1917). It has been found in stables (Ford, 1931) and flying about old wooden steps (Sich, 1903). Other records are: in dried roots of anemone in Holland (van Poeteren, 1935), in old plums and apples in Italy (Della Beffa, 1935), in grain (Cotton & Good, 1937; Patton, 1931; Zacher, 1941, 1951), and in dried mushrooms (Krause, 1916).

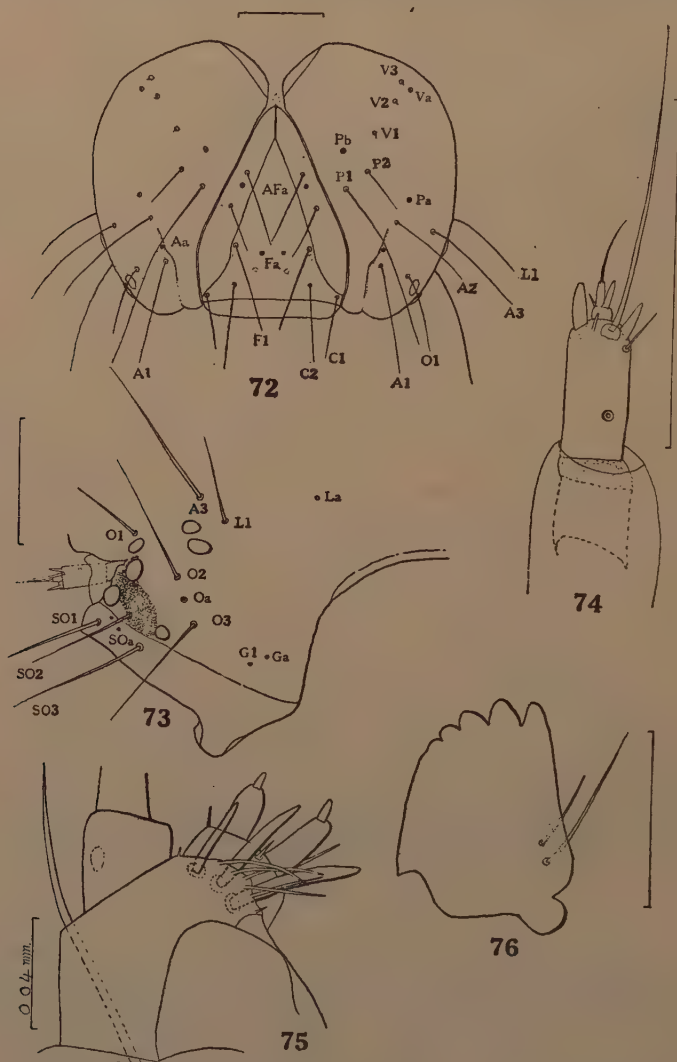
The species is well known as a pest of wine corks in damp cellars (Bender, 1941; Petersen, 1953; van Poeteren, 1932; Stellwaag, 1924a, 1924b; Zacher, 1927). Its life-history and habits have been described by Bender (1941) and Stellwaag (1924a, 1924b).

The following parasites have been recorded from it: *Apanteles* sp. (Schütze & Roman, 1931), *A. decorus* (Hal.) (Schütze & Roman, 1931), *Coelopisthia vitripennis* Thoms. (Falcoz, 1926), *Lissonota segmentator* (F.) (Morley & Rait-Smith, 1933), *Meteorus ruficeps* (Nees) (Stellwaag, 1924b), and the Tachinid, *Arrhinomyia cloacellae* Kram. (Baer, 1920-21).

Nemapogon granella (Linnaeus) (1758) (figs. 72-88).

Mature larva. Length, 7-9 mm.; breadth, 1.2-1.6 mm.

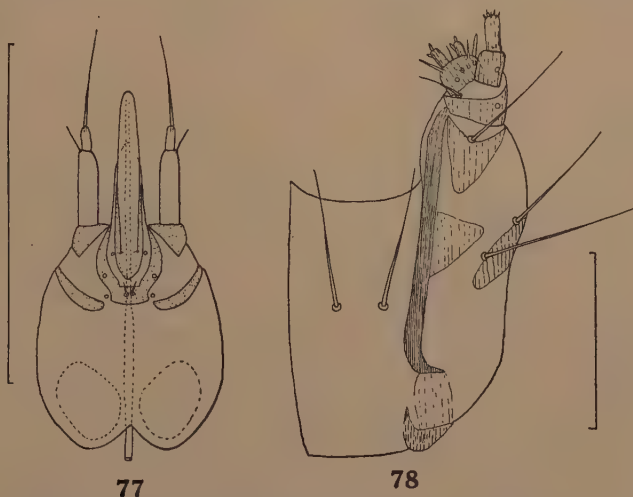
Head moderately dark brown to moderately pale yellowish or reddish brown; posterior region not darker or only with occipital margin darker; adfrontal areas



Figs. 72-76.—*Nemapogon granella* (L.), mature larva. (72) Dorsal view of head. (73) Ocellar region of left side of head. (74) Right antenna. (75) Dorsal view of apex of left maxillary lobe. (76) Ventral view of left mandible.

usually, and central part of fronto-clypeal apotome often, darker; eye-spot (fig. 73) not extending beyond third and fourth ocelli in the area between these and first and second ocelli; tergal plates of prothorax moderately pale to pale brown or yellowish; dorsal surface of legs pale yellowish brown; peritreme of spiracles moderately pale brownish; cuticle elsewhere white or nearly white with pinnacula

very indistinct (mag. $\times 75$) or not visible and with dense microtrichia (fig. 83). Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending nearly three-fourths of distance to vertical triangle; each side with six convex ocellar lenses, as shown (fig. 73); surface with reticulate microsculpture feebly impressed and with fine, indistinct, irregularly distributed rugae; most specimens with a slight but distinct, obliquely longitudinal carina above A1 and Aa (fig. 72). Coxae of all legs widely separated; pinnacula of V1 setae fused to coxae. Ventral prolegs usually with 19–21 crochets. Spiracles circular; spiracles of eighth abdominal segment a fourth or fifth larger than those of seventh and very nearly as large as those of prothorax. *Chaetotaxy*. Head as shown in figs. 72–73. Prothorax (fig. 85) with SV setae in a nearly horizontal line and on the same pinnaculum. Metathorax setose like mesothorax (fig. 79). Setae of abdomen as



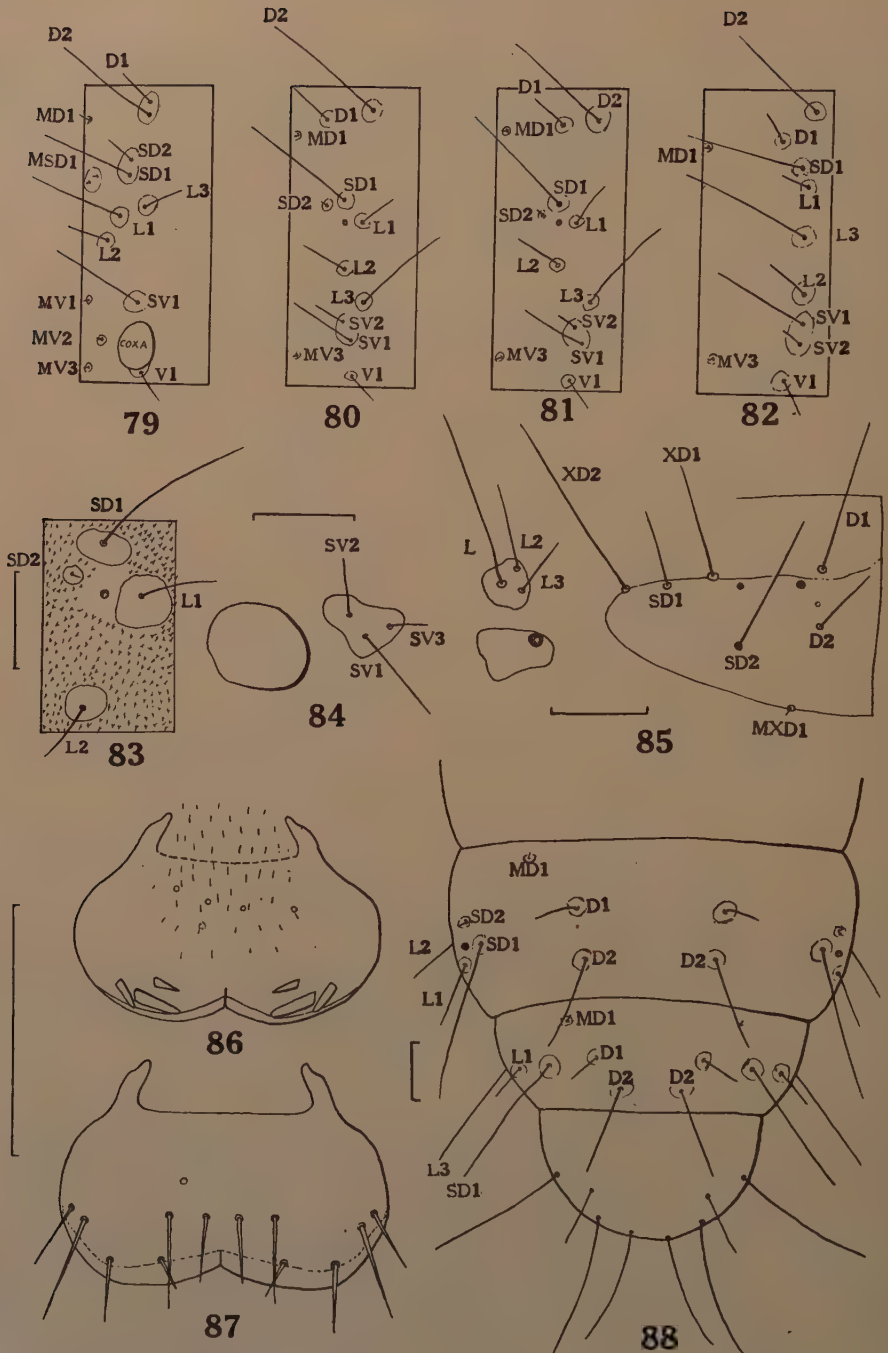
Figs. 77–78.—*Nemapogon granella* (L.), mature larva.
(77) Ventral view of prementum. (78) Ventral view of left maxilla and postmentum.

in figs. 80–84; SV group of 2–6 segments trisetose (fig. 84) and SV group of 1 and 7–9 bisetose, as in other members of the *N. granella* group.

Distribution. Nearly cosmopolitan.

Comparative notes. It is readily distinguished from *N. ruricolella* (Staint.) by having SD1 of the prothorax nearly as far from XD1 as from XD2, and from both the latter and *N. emortuella* (Zell.) by not having the posterior region of the head darkened. It may be distinguished from *N. cloacella* (Haw.) by its eye-spot (fig. 73), which does not extend beyond the third and fourth ocelli in the region between these and the first and second ocelli. From *N. ruricolella* and *N. cloacella* it may usually be distinguished by the much more distinct carina above A1 and Aa (fig. 72), but in some larvae of *N. granella* this carina is not distinct. It differs from *N. infimella* as shown under the heading of the latter species.

Habits. It is common out-of-doors in fungi. It has been bred by me in *Polyporus sulphureus* and others have found it in *Polyporus squamosus* (Pierce & Metcalfe, 1934a), *Polystictus versicolor* (Schütze, 1931), and other fungi (Petersen, 1953; Spuler, 1910). It has also been found in dried mushrooms. It is



Figs. 79-88.—*Nemapogon granella* (L.), mature larva. (79) Mesothorax. (80) Seventh abdominal segment. (81) Eighth abdominal segment. (82) Ninth abdominal segment. (83) Spiracle and associated setae of left side of sixth abdominal segment. (84) Proleg of sixth abdominal segment and SV group. (85) Dorsal and lateral setae of left side of prothorax. (86) Ventral view of labrum. (87) Dorsal view of same. (88) Dorsal view of eighth, ninth, and tenth abdominal segments.

best known as a pest of grain and other stored cereals, particularly when the moisture content of these is high. It has been recorded in mills, granaries, and warehouses in Britain (Barrett, 1887*b*; Bower, 1898; Roebuck, 1937; Waters, 1928), most parts of Europe (Anon., 1931, 1949; Candura, 1937, 1950; Hanke, 1931; Nonell Comas & Bertrán Olivella, 1927; Ogijewicz, 1934; Schulze, 1941; Tosi, 1929; Wolfram, 1952; Zacher, 1938, 1941, 1951; Zwölfer, 1928), in the U.S.S.R. (Bugdanov, 1932; Gavalov, 1927; Krasil'shchik, 1915; Porchinskiĭ, 1913; Shmal'ko 1939; Sudeikin, 1913; Zvérezomb-Zubkovskii, 1917, 1918), Algeria (Bouclier-Maurin, 1923), Japan (Kuwayama, 1928), Formosa (Takahashi, 1937), United States (Britton, 1918; Felt, 1915; Ryan, 1944), and Argentina (Brèthes, 1918). It may sometimes bore in the decayed wooden structures of warahouses, granaries, and other buildings (*e.g.*, Barrett, 1888). It has been found in biscuits in the U.S.S.R. (Averin, 1915), in chestnuts in Italy (Della Beffa, 1935), in dried roots of anemone in Holland (van Poeteren, 1935), in stored dates in the United States (Stickney, Barnes & Simmons, 1950), in Britain in bitter almonds and ergot of rye (Wakely, 1935), pistachio nuts (Richards & Herford, 1930), and in stored bird guano (Hinton & Greenslade, 1943), in cigars in Silesia (Seidel, 1930), and feeding on a paste of rye flour and dextrine in France (de Joannis, 1917). Other commodities on which it has been found besides stored wheat, rye, maize, rice, bran, and sharps are clover seed, hazel nuts, groundnuts, dried bilberries, dried peaches, and dried cherries.

N. granella, like *N. cloacella*, is a well-known pest in wine cellars, where the larvae bore in the wine corks (Bender, 1941; Schneider-Orelli, 1913; Stellwaag, 1924*a*, 1924*b*).

In North Germany and in northern Europe generally it is largely replaced as a pest of stored grain and other cereals by *N. infimella* (Zacher, 1951). Grain infested by *N. granella* is especially liable to attack by mites, and it has been suggested that a partial explanation of this may be that the excreta of the larvae tend to raise the moisture content of the material (Rodionov, 1940). Accounts of its biology have been given by Bender (1941), Hanke (1931), Stellwaag (1924*a*), Tosi (1929), and Zacher (1927, 1938, 1941).

The following parasites have been recorded from it: *Dibrachys cavus* (Walk.), *Hemiteles bipunctator* Thunb. (Schütze & Roman, 1931), *Apanteles* sp. (Schütze & Roman, 1931), and *Nemeritis canescens* (Grav.) (Hase, 1937). In granaries in Italy no hymenopterous parasites were observed, and its chief enemy appeared to be the mite, *Pediculoides ventricosus* (Newp.) (Tosi, 1929).

Nemapogon infimella (Herrich-Schäffer) (1851).

Mature larva. More or less identical with *N. granella* (L.) in size, colour and external structure, but with L1 of head separated from second ocellus by one-and-a-half to two or more times the diameter of the ocellus. This difference is sufficient to distinguish between series of the two species, but occasional individuals of *N. infimella* have L1 as close to the second ocellus as those larvae of *N. granella* in which L1 is exceptionally far behind the second ocellus. In a series of *N. infimella* bred from chestnut the pinnaculum of SD2 of the first eight abdominal segments was very close to that of SD1 and sometimes more or less fused to it. In another series bred from on *Polyporus sulphureus*, however, the pinnacula of the two SD setae were as widely separated as they normally are in *N. granella* (fig. 83).

Distribution. Europe.

Habits. Larvae have been found by me in the field on many kinds of fungi, including *Polystictus versicolor* and *Polyporus sulphureus*. It has also been found frequently by me in decayed wood and on one occasion was bred from stored

chestnuts. It has been bred from *Polyporus squamosus* (Pierce & Metcalfe, 1934a) and other fungi (Zacher, 1939, 1941).

In northern Europe it largely replaces *N. granella* in grain stores. It is common in grain stores in Sweden, especially when the moisture content of the grain is above 14 per cent. Its preference for grain seems to be: rye>wheat>barley>oats, but it also develops in maize, bran and seeds of grass, clover and flax (Mathlein, 1941a). It seems to have been first recorded as a pest of stored products when it was found in rye in Germany and given the name, "*Tinea secalella*" by Zacher (1938). Other records of its occurrence in grain are given by Anon. (1949), Mathlein (1941b), Petersen (1953) and Zacher (1941, 1942, 1951). Notes on its life-history have been given by Mathlein (1941a) and Zacher (1941, 1942).

The following parasites have been recorded from it: *Meteorus atrator* (Curt.), and possibly *Chremylus rubiginosus* (Nees) (Zacher, 1942), and *Meteorus pulchricornis* (Wesm.) and *Horogenes fenestralis* (Holmgr.) (referred to as *Angitia fenestralis* (Holmgr.)) (Zacher, 1941, 1942).

***Tineola bisselliella* (Hummel) (1823) (figs. 89-93).**

Mature larva. Length, 7-9 mm.; breadth, 1.5-1.9 mm.

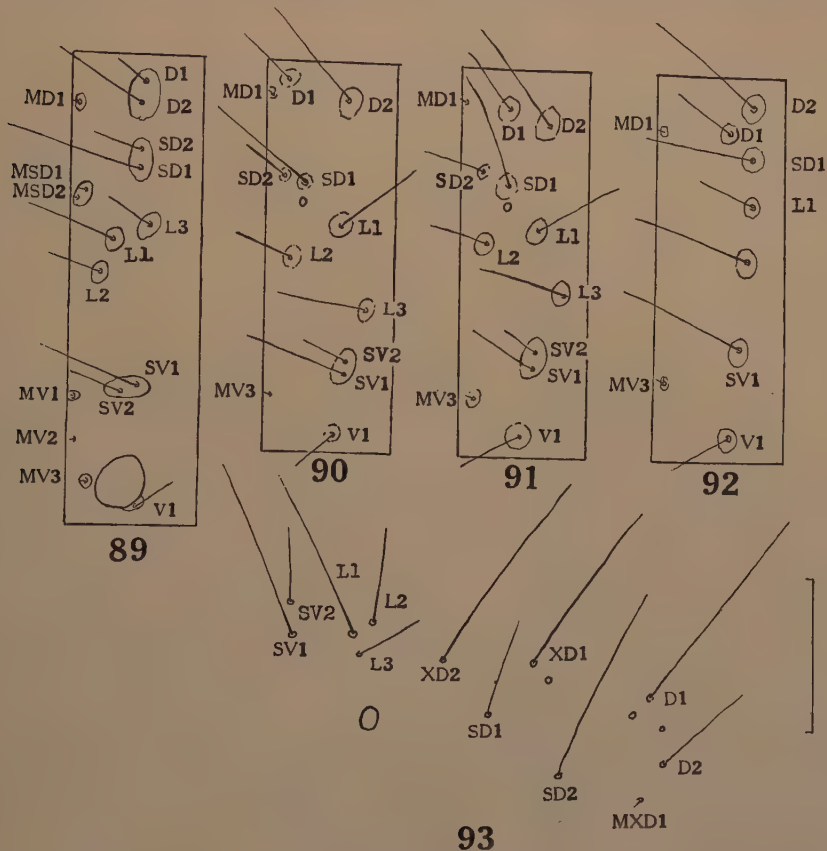
Head moderately pale to moderately dark yellowish brown with anterior margin, meso-ventral margin, and occipital margin usually distinctly darker, sometimes nearly black; adfrontal area darker brown than adjoining cranial areas; tergal plates of prothorax usually pale brown or pale yellowish brown; parts of dorsal surface of legs pale yellowish brown; peritreme of spiracles pale brown; cuticle elsewhere white or nearly white with pinacula indistinct even in stained specimens; surface of cuticle with dense, microscopic, usually flat-topped tubercles. Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending three-fourths of distance to vertical triangle and posteriorly long and very narrow; without convex ocellar lenses and usually without visible (mag. $\times 75$) pigment spots; surface of head microscopically reticulate or, posteriorly and sides, microscopically punctate; surface also with very fine, sparse, irregular, transverse rugae. Coxae of all legs widely separated; pinacula of V1 setae fused to coxae of front and middle legs and usually but not always completely fused to coxae of hind legs. Ventral prolegs usually with 17-22 crochets. Spiracles of eighth abdominal segment scarcely noticeably larger than those of seventh segment and equal in size to those of prothorax. *Chaetotaxy.* AF1 as far from F1 as from AF2 to distinctly nearer F1; position of AFa very variable, sometimes half way between AF1 and AF2 but more usually nearer AF1 and sometimes even in front of it. V3 slightly further from V2 than is V1; Va in front of and laterad from V2; P2 far behind P1 and only slightly laterad from it, at level of AF2 or even slightly behind latter; Pb usually directly mesad from P2; Pa more or less directly laterad from P1. Aa laterad from and slightly behind A2, usually nearly as far from the latter as is A1 but sometimes much closer to A2. L1 slightly in front of level of P2. O2 slightly behind level of O3; Oa above and in front of O3. SO group forming an equilateral triangle with SOa in front of and between SO2 and SO3. Ga above and sometimes above and in front of G1. Prothorax as shown in fig. 93. Metathorax setose like mesothorax (fig. 89). Abdomen with setae as shown in figs. 90-92; SV group of segments 1 and 7-8 bisetose, of segments 2-6 trisetose, and of segment 9 unisetose; ninth segment with only two L setae.

Distribution. Cosmopolitan.

Comparative notes. From all other TINEINAE known to me that have not more or less fused coxae, it may be distinguished immediately by having the SV

group in a feebly oblique or nearly horizontal line instead of in a vertical or nearly vertical line. The presence of only two instead of three L setae on the ninth abdominal segment is a further important distinguishing feature of the genus.

The only even approximately correct illustrations known to me of the larva of the common clothes moth are those of Dampf (1910). In his figure of the head, AF1 and AF2 are slightly more widely separated than in any specimen



Figs. 89-93.—*Tineola bisselliella* (Hummel), mature larva. (89) Mesothorax. (90) Seventh abdominal segment. (91) Eighth abdominal segment. (92) Ninth abdominal segment. (93) Dorsal, lateral, and subventral setae of left side of prothorax.

seen by me, and he has omitted Ga and one of the SO setae. He has also omitted MXD1 on the prothorax and MD1 on the first and ninth abdominal segments.

Life-history and habits. Accounts of its life-history and habits have been given by many writers, e.g. in Australia (Anon., 1941; Jenkins, 1944; Miller, 1948), Europe (Bruneteau, 1930; Busvine, 1951; Kemper, 1934, 1935; Moncrieff, 1950; Nagel, 1920; Notini, 1939; Ossipov, 1915; Titschack, 1922, 1926b; Zacher, 1927), Japan (Yamada, 1938), and North America (Back, 1935; Back & Cotton, 1931; Benedict, 1917, 1918; Doner & Thomssen, 1943; Griswold, 1944; Lesser, 1949; Mallis, 1954; Marlatt, 1915; Smulyan, 1919; Walker, 1944). Of these accounts,

those of Griswold, Kemper, and Titschack are the most useful. Methods of rearing large numbers for use in experimental work are described by a number of writers (*e.g.* Cox, 1944; Goddin in Campbell & Moulton, 1943, pp. 53-54; Griswold, 1933, 1934; Gösswald, 1937; Haydak, 1947), and Ballard & Davidson (1954) describe a method of controlling mites in cultures.

The duration of the egg stage is as follows: 37.2 days at 12.8°C. (55°F.), 13.8 days at 18.3°C. (65°F.), 6.9 days at 23.9°C. (75°F.), and 5.2 days at 29.4°C. (85°F.) (Griswold, 1944). Essentially similar figures are given by Titschack (1927) and others. The duration of the egg stage is hardly affected by differences of relative humidity within the range 20 to 100 per cent. (Griswold, 1944). The duration of the larval stage varies both according to temperature and to the quality and quantity of food available. Titschack records the following, 186 to 195 days at 15°C., 123 to 135 days at 20°C., 72 to 89 days at 25°C., and 62 to 72 days at 30°C. However, on fish meal males complete their development from egg to adult in 45 to 59 days and females in 48 to 59 days at 25°C. (Griswold, 1944). Frohawk (1887) records a larval stage of 1,166 days when fed on feathers. The larvae may, perhaps, diapause. For instance, they may remain without feeding within "resting cocoons" for as long as four months (Griswold, 1944), but nothing is known of the factors that initiate diapause if the species does indeed diapause.

The duration of the pupal stage is as follows: 49 to 54 days at 12.8°C. (55°F.), 19 to 24 days at 18.3°C. (65°F.), and 11 to 13 days at 23.9°C. (75°F.) (Griswold, 1944). Titschack (1927) found the duration of the pupal stage to be 20 days at 20°C. and 10 days at 30°C. Further information about the speed of development at different temperatures has been given by Titschack (1925, 1936). Rawle (1951) has shown that development and reproduction occur at temperatures as high as 33°C., that the eggs would hatch at 35°C., and that at 41°C. all stages were killed within 4 hours. She found that the males became sterile in two days or less at 35°C. Some notes on the resistance of *Tineola* to prolonged cold spells are given by Mansbridge (1936). At 25°C. the optimum relative humidity for both males and females is 75 per cent. (Griswold & Crowell, 1936). At this humidity the speed of development was greatest, the highest percentage of larvae completed their development, and both male and female adults lived longer than at any other humidity.

The male adults live longer than the female adults (Griswold, 1931, 1944; Griswold & Crowell, 1936; Titschack, 1926a, 1936). For instance, at 25°C. and 75 per cent. R.H. the males live 31 to 33 days and the females 19 or 20 days. Virgin females live longer than mated ones, but the length of life of both sexes is dependent upon body weight at any given temperature or relative humidity within the normal range, as shown by Titschack:

		20°C.	30°C.
Virgin females	0.8-1.9 mg.	12	6
	2.0-2.9 "	22	8
	3.0-4.9 "	28	8
Mated females	0.8-1.9 "	10	5
	2.0-3.9 "	13	6

Mating takes place very soon after emergence from the pupa. The female produces a scent from abdominal glands that attracts the male and induces courtship behaviour. A single isolated female abdomen is effective in attracting males over a distance of about 1.5 cm. (Roth & Willis, 1952). The females fly much less readily than the males, so that most of those seen flying are males. Hase (1942) describes baits for trapping.

The female begins to oviposit within a day or so of mating. The number of eggs laid depends upon the size of the female and other circumstances, but

usually about 100 eggs are laid. Titschack (1922) records one female that laid a total of 221 eggs. The female lays eggs every day or every few days until a day or so before it dies. The average number of eggs laid per day is about five to seven. The record number of eggs laid by a single female in one day appears to be 59 (Back & Cotton, 1931). The surface sculpture of the egg is described by Lehmensick & Liebers (1937) and others. The eggs are laid singly or in groups of two or more either upon the surface of fabrics or inserted between the strands of wool in materials of a more open texture. In furs and skins they are laid at the base of the hairs. The eggs are not firmly glued to the substrate, and they can easily be dislodged by shaking or brushing.

The larvae may begin to spin webbing within a day or so of hatching, or they may wander about for several days without spinning. They usually spin delicate tubes open at both ends in which they crawl about freely. They never construct portable cases. Sometimes flat mats are spun beneath which the larvae crawl about. As Griswold (1944) says, "The larvae spin silken strands and runways over the material on which they are feeding. If the food is in powdered form, it soon becomes entangled in a mass of silken threads. It is this larval habit of spinning webbing that has given *Tineola bisselliella* one of its common names, that of 'webbing clothes moth'. Often the runways are in the form of tubes that are several inches in length. Sometimes the tubes are held in position by silken guy lines. Intermingled with the webbing are bits of debris of various kinds, such as particles of food material, cast skins, and pellets of excrement. The larvae also make tough, cylindrical cases within which they rest or moult. These cases are quite different in appearance from the neat, portable cases constructed by the case-making clothes moth, *Tinea pellionella* (L.). The cases of *Tineola bisselliella* usually have an untidy look, for they are generally covered from one end to the other with all sorts of debris, particles of food material, pellets of excrement, cast skins, and old head capsules. Occasionally the larvae remain in their tough silken cases for considerable periods of time." The larvae do not always remain in their tubes or runways, but may leave them and wander about, particularly if the food there available is unsatisfactory.

There are apparently never normally less than five larval instars. The number of larval instars is closely correlated with the developmental period. When the period from egg to adult is 60 days or less there are rarely more than five instars, but 12 instars have been recorded for a developmental period from egg to adult of 237 days. The maximum number of larval instars recorded is 41 (Titschack, 1926b). As in many lepidopterous larvae, the head capsule is shed separately in the early instars but at the last moult is attached to the shed body cuticle.

A new type of cage for containing the larvae is described by Colman (1932a), who points out (Colman, 1940) that the newly hatched larva can pass through an 0.004 inch opening.

It has been recorded infesting a wide variety of products, chiefly those of animal origin. No attempt has been made to catalogue all such records, but the following may be mentioned: raw wool or woollen materials (Anon., 1943; Back, 1946; Herrick, 1933; Smit, 1931; Walker, 1944), woollen fluff in hot-air shafts in houses (Spencer, 1931), house insulation made of cattle hair (Back, 1939), upholstered furniture (Back & Cotton, 1926, 1930, 1931), bristles (Meldola, 1897), feathers (Griswold, 1944), wire insulation of a telephone exchange (Curwen, 1931, 1932), drugs containing albumin (Madel, 1939), and dried blood albumin (Fisher, 1942). As might be expected, it is sometimes a serious pest of museum collections. For instance, it has been recorded attacking skins of birds and mammals (Austen & Hughes, 1932), skins of snakes (Vollmer, 1931), and entomological collections (Frickhinger, 1920; Howard & Marlatt, 1896). It has also been found in the den of a rat-snake in a zoological garden (Sich, 1913). In short,

it will attack all kinds of furs, skins, and feathers or commodities containing these. Its development on different kinds of furs is described by Kemper (1936) and the susceptibility of different kinds of animal fibres to its attack by Burgess & Poole (1931). In 1951, it was found in England on Norwegian whalemeat that had been in store for one year.

T. bisselliella will also occasionally breed in dry bread and in stored cereals of various kinds. It has been recorded in stored maize (Swenk, 1922) and in oats and barley (Laing, 1932). In 1951, it was found in England in Turkish pollards and in Turkish cottonseed cake. It has been said to infest sugar (Dingler, 1928), but, as pointed out by Griswold (1944), this record is based on a few specimens which had probably come from a piece of woollen material near at hand. Instances of cross infestation are common enough. For instance, specimens have been found in Australian flour in a ship in London, but these had almost certainly come from wool stored in the same hold.

Larvae can injure synthetic fibres such as aralac and nylon (Griswold, 1944; Patton, 1945), but they cannot maintain themselves on such materials.

It is sometimes found breeding in the nests of house-sparrows, particularly in the Holarctic Region (e.g. Linsley, 1944, 1946; Woodroffe, 1953; Woodroffe & Southgate, 1951a). Since these nests are common about building structures of one kind or another, they should not be overlooked in the control of *Tineola*, for they serve to maintain small and widely distributed populations that may at any time serve as foci for infestations of stored products. In England, it has also been found breeding in the nest of the pied wagtail (Woodroffe & Southgate, 1951a). I have never been able to find it breeding in bird nests out-of-doors in England or anywhere else except about buildings, and Mr. E. B. Basden (personal communication) has had the same experience. In milder climates, however, it is known to breed in the field. It has been found in the nests of *Anthophora linsleyi* Timberlake in California (Linsley & MacSwain, 1942a, 1942b), where it is a scavenger living on excess pollen and remains of bees in old cells and does not injure the bee.

The larva may become cannibalistic when food is insufficient or too dry, and it is recorded eating the pupae of its own species (Illingworth, 1917). It has been reported attacking mites (Pergande in Ewing, 1914) and eggs and living larvae of ticks (Vollmer, 1931).

In the Holarctic Region, *Tineola bisselliella* is one of the most important, if not actually the most important, insect pest of furs, woollens, and feathers or commodities containing these materials. It may be of African origin (Meyrick, 1928), but is now cosmopolitan. It was certainly introduced into North America before 1860, when it was described as *Tinea lanariella* by Clemens, and there is evidence to believe that it is the clothes moth referred to by writers in North America in the middle of the eighteenth century. In Canada it was the common clothes moth as early as 1892 (Fletcher, 1893). In the Nearctic, as in the Palaearctic, it gradually decreases in importance as a pest of keratin-containing materials as one goes South. In this connection it is of interest to note that it has for long been established in Australia and New Zealand, where it is a very important pest, but it appears to be of little importance in the warmer parts of the world.

It is of great interest to note that Titschack (1922), Griswold (1944), and others have shown conclusively that keratin is not only unnecessary for *Tineola*, but when fed on feathers and animal hair its growth is much slower and its mortality much higher than on many other foods commonly available in its ecological niche (indoors), e.g. stored cereals of many kinds, fish or meat meals, and other substances. For instance, at similar temperatures and humidities its development is much faster and its mortality lower on fish meal, whole-meal, and even on flour of low extraction (72%) than on woollen materials though these

be stained with urine and sweat. One of the reasons for the poor development of *Tineola* on keratin is that this protein is very poor in such important amino acids as tryptophane, methionine, histidine, and lysine. Furthermore, if keratins possess any vitamins of the B complex these are present only in insignificant quantities.

It is a matter of common observation that the most serious attacks by *Tineola* are generally developed on the parts of woollen garments that are stained with urine or sweat. The reason for this is that most of the vitamins of the B complex are excreted in urine, and thiamine, riboflavin, niacin, and pantothenic acid are lost in sweat. The amounts lost in sweat are very small in relation to the requirements of *Tineola*, but, as suggested by Fraenkel & Blewett (1946), it is conceivable that over a period significant amounts would be concentrated in certain parts of unwashed garments.

Although the most serious attacks by *Tineola* are on those parts of woollens that are stained with urine or sweat, any part of a woollen garment may be extensively damaged. The female will oviposit on clean woollens on which no larvae or only a very small percentage will survive, but before they die they may nevertheless feed for a time and do considerable damage.

Perhaps the most important reason for the prominence of *Tineola* as a pest of stored products is to be found in the nature of the materials it attacks. Most stored products can support large populations of insects for considerable periods and the material not actually damaged or consumed can still retain its value. The sort of things usually attacked by *Tineola*, however, such as woollen clothes, may be made completely valueless by only a few larvae feeding for only a few days on a small part of the material.

The success of *Tineola* (and also *Tinea pellionella* (L.) and some other TINEIDAE) as a pest of keratins is also due to its remarkable ability to metabolise most of its water requirements. For instance, *Tineola* will complete its development in an atmosphere of 20 per cent. relative humidity, which for such materials as feathers corresponds to a moisture content of approximately 6 per cent. However, it does much better in a more humid atmosphere, such as 75 per cent. relative humidity, but even at that relative humidity the moisture content of feathers and scoured wool is in the neighbourhood of 12 per cent. The production of metabolic water by the larva is discussed by Mellanby (1934, 1936).

Vitamin requirements. The vitamin requirements of the larva are fairly well known. Early writers had noted the fact that yeast stimulated its growth (e.g., Billings, 1936; Colman, 1932*b*) and that part or all of the B complex was necessary for growth (Crowell & McCay, 1937). Fraenkel & Blewett (1946) claim that thiamine is not essential for growth, although this vitamin appears to have a beneficial effect. These writers have shown that *Tineola* is indifferent to the presence of carbohydrates in its diet and grows equally well on diets lacking carbohydrates. They suggest that since it does not require carbohydrate neither does it require thiamine to carry the carbohydrate through the essential pyruvic acid stage of its metabolism. The fact that it is indifferent to carbohydrates but is at the same time benefited by thiamine may, according to them, be due to the fact that thiamine has a rôle in carrying the deaminised residues of some of the amino acids through the pyruvic acid stage. It may be noted here that thiamine also functions as a co-enzyme in the metabolism of the glycerol part of fat, but these writers and Crowell & McCay (1937) have shown that *Tineola* is as indifferent to fat as it is to carbohydrate. These arguments are more teleological than rigorous, and I suspect that the tolerance of *Tineola* to a thiamine deficiency in its diet is due to the fact that part of its requirements of this vitamin are supplied by symbiotic micro-organisms. Until now, symbionts capable of synthesising vitamins have not been clearly demonstrated in any Lepidoptera, although such symbionts are widely distributed throughout the

orders of insects. In this connection it is of interest to note that it has recently been shown that *Azotobacter ſulci* in the fat-body of *Tineola* larvae is capable of fixing atmospheric nitrogen *in vitro* if not *in vivo* (Peklo & Šatava, 1950). It has also been shown that riboflavin is present in the larva of *Tineola* even when it is fed on a diet entirely free of riboflavin (Busnel & Drilhon, 1943). The larva is relatively insensitive to a riboflavin deficiency in its diet.

Niacin is essential for growth, the optimal amount being 8–16 μg per gram of food (Fraenkel and Blewett, 1946). Pyridoxine, choline, biotin and inositol are beneficial but not essential for complete development, para-aminobenzoic acid appears to be of no importance, but pantothenic acid is essential for complete development (Fraenkel & Blewett, 1946).

Digestion of keratin. Keratin is the chief constituent of fur, wool, feathers, horns and hoofs. The only animals definitely known to be capable of digesting keratins are the Mallophaga of birds, some DERMESTIDAE, some OECOPHORIDAE and some TINEIDAE. A brief summary of the work on keratin digestion is given by Hinton (1953). Much is now known of the way in which keratin is broken down in the gut of *Tineola bisselliella*. Keratin consists of long helical polypeptide chains. The side chains are S-S linkages, the cystine molecules being so arranged that the two halves of each molecule are in two principal adjacent chains and are connected by an S-S bond. Many other structural details of the keratin molecule are still in dispute (Astbury, 1953). Before ordinary proteinase can attack the polypeptide chains, the S-S bonds must be broken and the chains set free. If the keratin structure is loosened in alkaline solution by ionisation and penetration of water, reducing agents like thioglycollic acid can break the sulphur bridge by adding hydrogen to produce two molecules of cysteine from one of cystine: $\text{RS-SR} \rightarrow \text{RSH} + \text{HSR}$.

It has long been known that the larva can digest keratins (Titschack, 1922). In view of the importance of this species as a pest, it is not unnatural that most of the work on the digestion of keratins is concerned with it. By the middle 1930's the following notable points about the digestion of *Tineola* were established: the average pH of the mid-gut is 9.9 but is occasionally as high as 10.2 (Duspiva & Linderstrøm-Lang, 1935); the redox potential of the mid-gut was in the range -250 to -280 and possibly -300 mV (Linderstrøm-Lang & Duspiva, 1936); and that not only was the proteinase of *Tineola* insensitive to sulphhydryl groups but so also was that of the wax moth, proteinase of the latter species attacking keratin *in vitro* when a suitable reducing agent was present (Duspiva, 1936). The nature of the reducing agent in the gut was unknown to these writers. They tentatively suggested that wool might be reduced by a gut dehydrogenase. In recent years, this work has been greatly extended by a group of Australian workers.

Day (1951a) has shown that the larva bites the fibres of wool into 70 to 150 μ lengths. Freshly shorn wool, in which all the disulphide linkages are intact and in which no sulphhydryl groups are present, is completely digested. Proteinases extracted from the gut would not digest wool until it was partly reduced *in vitro*. Examination of the fibres in the mid-gut showed that behind the anterior fourth digestion began very rapidly. The existence of a strongly reducing middle zone in the mid-gut was confirmed with triphenyltetrazolium chloride. Further confirmation was had by the ingenious method of feeding the larvae wool that had been reduced and then cross-linked with mercuric cyanide, when it was found that behind the anterior fourth the mid-gut was abruptly blackened by the liberation of mercury sulphides following the rupture of the RS-Hg-SR linkages.

The mid-gut is very poorly supplied with tracheae as compared with that of some other caterpillars of similar size (Day, 1951b). A poor supply of tracheae to the mid-gut seems to be fairly characteristic of the insects that are capable of digesting keratins (Waterhouse, 1952d). It has been suggested that the very poor supply of atmospheric oxygen to the mid-gut is related to the need for

maintaining strongly reducing conditions here. Xanthine oxidase has been found in the gut. This enzyme is inhibited by oxygen. The hypoxanthine-uric acid reaction has one of the lowest redox potentials recorded in a biological system, and Day suggests that this reaction may be a factor in maintaining a low gut potential.

An analysis of the constituents of the excreta of the larva throws some light on its process of digestion. The nitrogen partition as percentages of the total non-protein nitrogen in the dry excreta was found to be: uric acid N 77.5 per cent., ammonia N 20.7 per cent. and urea N 1.8 per cent. (Hollande & Cordebar, 1926). More recently, a careful analysis of the constituents of the excreta has been made by Powning (1953). The percentages (dry wt. basis) of the following may be noted, uric acid 41, ammonia 4.1, urea 3, total sulphur 4.5, soluble sulphur 3.1, total cystine 10, and soluble cystine 6.2. Of the total water-soluble sulphur, 55 per cent. is cystine sulphur and only 8 per cent. sulphate sulphur. Unexpectedly little use is made of ammonia in the excretion of sulphate, and Powning shows that only 0.1 per cent. ammonia is required to combine with the small quantity of sulphate in the excreta. In view of the highly reducing nature of the digestive juice, the excretion of cystine rather than cysteine is at first sight surprising. However, the redox potential of the hind-gut is +250 mV (Waterhouse, 1952c). It has been suggested (Hinton, 1953) that the significance of the excretion of cystine rather than cysteine may lie in the fact that for each molecule of cystine formed a molecule of water is liberated; and not only does *Tineola* usually live in rather dry environments, but the moisture content of its food tends to be unusually low.

When the larva is fed on nickel-treated fabric, it excretes much less cystine sulphur than when it is fed on untreated wool. This shows that hydrogen sulphide is produced, as has been shown by Waterhouse (1952a). It had previously been suggested (Powning, Day & Irzykiewicz, 1951) that the ability of *Tineola* to digest keratins was due to the reducing power of the digestive fluid and its high pH rather than to any peculiarity of its proteinase. The production of free H_2S in the gut suggests the presence of an enzyme of the cysteine desulphydrase type, and an *in vitro* demonstration on an enzyme from the larval gut that is capable of liberating H_2S from L-cysteine has been made (Powning, 1954). The larva has a very active desulphydrase concentrated mostly in the gut. Cystine, methionine, homocysteine, and glutathione do not function as substrates for this enzyme. The liberation of free H_2S is a very peculiar feature, and, in view of its toxicity, almost suggests that the usual cytochrome system is lacking in the mid-gut epithelium, which is certainly more poorly supplied with tracheae than most insect tissues. It may be noted here that other keratin feeders either have no desulphydrase in the gut or, *e.g.* *Attagenus*, only a relatively weak one, and thus excrete large amounts of cystine as compared with *Tineola*.

It is of interest to note here that it has been found that woollen fabrics can be protected by first reducing the S-S bonds to SH groups and then re-oxidising the fabric with an aliphatic dihalide to re-establish the S-S bonds in a form that cannot so easily be reduced by the larva (Geiger & others, 1941). For instance, if the disulphide linkages are replaced by bisthioether linkages ($RS-(CH_2)_n-SR$), the wool becomes resistant to moth attack in proportion to the number of linkages altered and still retains its chief physical attributes (Geiger, Kobayashi & Harris, 1942; Hartley, Elsworth & Barritt, 1943). Summaries of work on moth-proofing textiles are given by Lesser (1949) and Moncrieff (1950).

Detoxication and storage excretion. In the mid-gut of lepidopterous larvae there are large broadly oval to long and narrow cells, each of which has a large cavity that may occupy the larger part of the volume of the cell. These cells are

known as goblet cells. They are not known to occur in any other order of insects, and in the Lepidoptera have so far been reported only in the suborder Ditrysia. The goblet cavity is closed on the lumen side by a fine membrane, and it is not continuous with the lumen of the gut. The lumen side of the goblet cell lacks the striated border of the columnar cells. The cavity does not contain cytoplasm, but the nature of the fluid it contains is unknown. The goblet cells are, as a rule, separated from one another by one or more columnar cells. In *Tineola*, the goblet cells are much more numerous in the anterior and posterior thirds than in the middle third of the mid-gut (Lotmar, 1941a). The histology and function of the goblet cells of *Tineola* has been investigated by Waterhouse (1952a, 1952b) who has shown that they play an important part in storage excretion and in the detoxication of certain poisonous metals and other elements.

Waterhouse investigated the fate of 30 metallic and 5 non-metallic elements after ingestion by *Tineola* larvae. By suitable treatment with metal salts, the chemically reduced wool can be re-oxidised so that the disulphide linkages are formed again in such a way that pairs of sulphur atoms are linked through a metal (wool-S-metal-S-wool). When wool thus treated is fed to the larvae, the disulphide bonds are broken and coloured metal sulphides are liberated in the gut. Larvae fed for several days on wool treated as described were dissected or sectioned, and the location of the coloured metal accumulations was noted. Cystine is present in such large amounts in wool that only part of it is utilized by the larva. That reduced in the gut is hydrolysed to give H_2S , and it is the sulphur of the unutilised cystine that combines with the metal of the metal-linked fabric to give a sulphide. Many metals expected to harm the larvae did not do so. The formation of sulphides detoxifies toxic metal ions.

Tellurium, and metals such as iron, nickel, copper, zinc, lead and gold, also capable of forming insoluble sulphides, accumulated in the goblet cell cavities. Other elements, e.g., aluminium, cerium, and chromium produce no mid-gut accumulations because their sulphides are rapidly hydrolysed. Manganese also did not form a sulphide, perhaps because the pH of the gut was too high.

The available evidence suggests that the goblet cell cavities are closed, and at first sight it would therefore appear that the insoluble sulphides found in them must be formed there. However, Waterhouse believes that they are absorbed through the cell membranes. It is suggested that the amino acids and peptides liberated during digestion form an extremely finely divided colloidal dispersion of a part of the metal sulphides in the lumen of the gut. The sulphides so dispersed are absorbed, and the remainder are excreted.

It seems likely that most of the products of digestion are absorbed by the columnar cells, as the total surface area they expose to the lumen is so very much greater than that exposed by the goblet cells. Waterhouse suggests that the sulphides may be absorbed by the columnar cells and passed entirely to the goblet cells, which then discharge them into their cavities. In the middle region of the mid-gut most of the columnar cells are not in contact with goblet cells as they are in the anterior and posterior regions; and in conformity with this fact, the goblet cells of the middle part of the mid-gut accumulate less sulphides than those at either end.

All goblet cells together with their contents are shed into the lumen of the gut during the periodic total renovations of the epithelium. These cells thus function in storage excretion. If periodic discharges occur between moults of the sulphides in the goblet cell cavities, they cannot occur more often than once every two or three days, according to the observations of Waterhouse. Even if it were to be shown that the cavities of the goblet cells have a narrow opening into the gut lumen, it is difficult to see how they could discharge into the gut lumen without also discharging the sulphides.

Iron and copper either have the colour of their sulphides masked in some way

in the goblet cell cavities, or else occur in these cavities in some other form. Barium and beryllium form readily hydrolysable sulphides but insoluble phosphates. Some evidence is given by Waterhouse that these may be detoxified by forming phosphates. It is also suggested that excess calcium and magnesium may be deposited as phosphate granules in the columnar and goblet cells. Beryllium is less toxic to *Tineola* than it is to most insects. Beryllium inhibits magnesium-activated enzymes. Little alkaline phosphatase is found in the mid-gut epithelium of *Tineola* (Day, 1949), and it is this fact that may explain the low toxicity of beryllium for *Tineola*.

Wool dipped in 1 to 4 per cent. sodium fluoride is relatively distasteful to the larvae and kills a high percentage, but some survive for a time. When sufficient calcium is present in the wool to permit the formation of calcium granules, these granules accumulate near the lumen border of the columnar cells of the anterior and posterior regions of the mid-gut. It is possible that small amounts of ingested fluoride can be detoxicated by being deposited as calcium fluoride in the calcium granules. However, the amount of calcium in wool is small and a stage is soon reached when all ingested fluoride cannot be detoxified. In this connection it is significant, as Waterhouse has pointed out, that fluorides, chiefly silico-fluorides, are the only inorganic materials that are widely used for moth-proofing fabric.

Differences were found in the behaviour of the goblet cells. Staining the mid-gut for ferric iron showed no staining in the middle region, heaviest staining in the posterior, and lighter staining in the anterior region. The goblet cells of these three regions of the mid-gut also differ in structure. A remarkable difference was noted in the behaviour of the goblet cells in the posterior and anterior regions to different metals. For instance, those of the posterior region all accumulate iron when the concentration of iron in the diet is low, but only those of the anterior region accumulate nickel unless the concentration of nickel is high; and mercury is accumulated by only a few of those that ordinarily accumulate nickel. In short, cells that appear to be identical and behave similarly to one metal behave differently to other metals. The columnar cells also behave differently, since, as already stated, those of the anterior and posterior regions accumulate granules not present in the middle region.

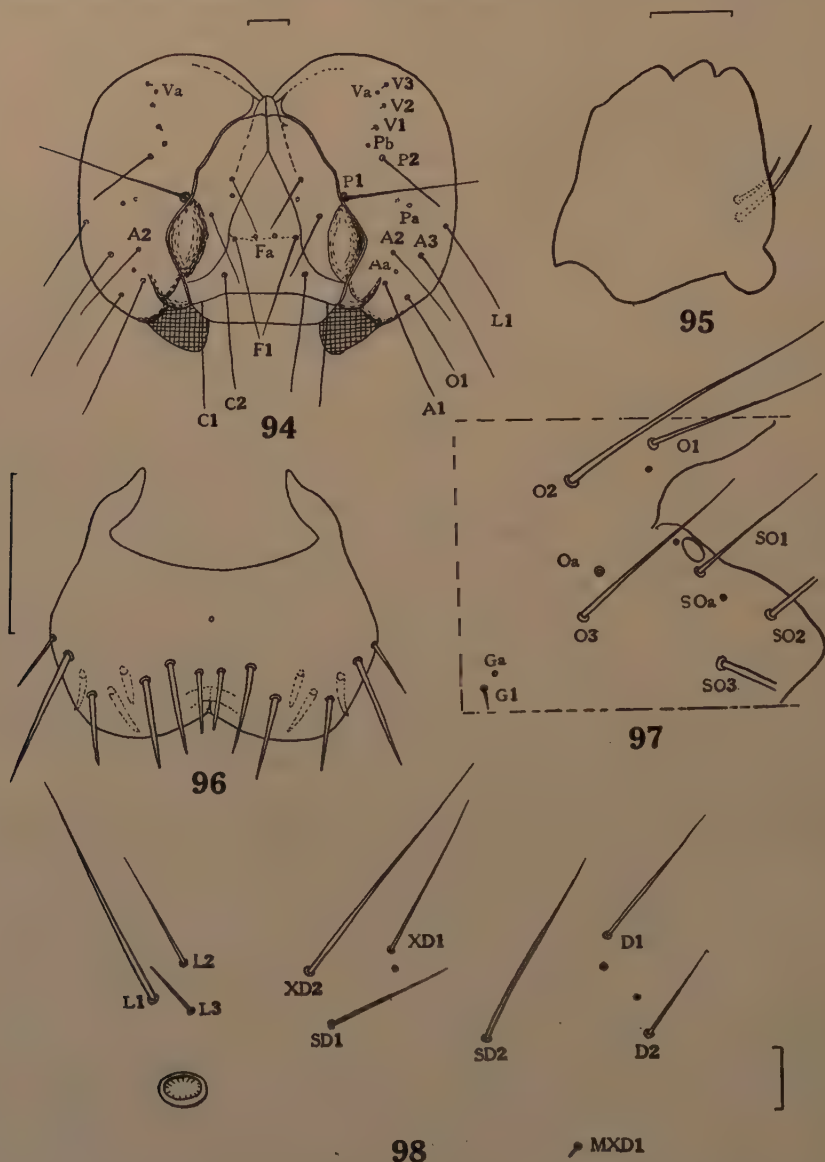
Predators and parasites. Probably the most important predator of the larva, both in Europe and North America, is the larva of the fly, *Scenopinus fenestralis* (L.). Attacks by *Scenopinus* larvae have been seen by Griswold (1944), and on several occasions I have found *Scenopinus* larvae in furs where their only possible prey was *Tineola*. The mite, *Pediculoides ventricosus* (Newp.); attacks the newly emerged adults (Herfs, 1926) as well as other stages (Geigy & Zinkernagel, 1941; Notini, 1939). Another mite, *Typhlodromus tineivorus* Oudm., also attacks it (Geigy & Zinkernagel, 1941). A species of *Nosema* (Geigy & Zinkernagel, 1941; Lotmar, 1941a, 1941b) and a polyhedral virus attack the larva (Lotmar, 1941c; Smith & Xeros, 1954).

The following hymenopterous parasites have been recorded from the larva: *Apanteles carpatus* (Say) (Burks, 1943; Notini, 1939; Wilkinson, 1934); *Meteorus cespitator* (Thunb.) (= *atrator* (Curtis)) (Ferrière, 1941; Sachtleben, 1941); *Tetrastichus carpatus* Burks (Fallis, 1942), as a parasite of *Apanteles carpatus* (Say) in *Tineola* larvae (Burks, 1943), and as primary parasite of *Tineola* larvae (Back, 1945); *Tetrastichus tineivorus* Ferr. (Ferrière, 1941); *Hemiteles cinctus* (L.) (Notini, 1939) and from material infested by *Tineola* (Richards, 1949); *Hemiteles bipunctator* (Thunb.) (= *cingulator* Grav.) (Notini, 1939).

***Amydria vastella* (Zeller) (1852) (figs. 94-102).**

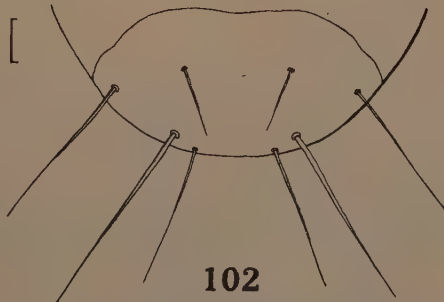
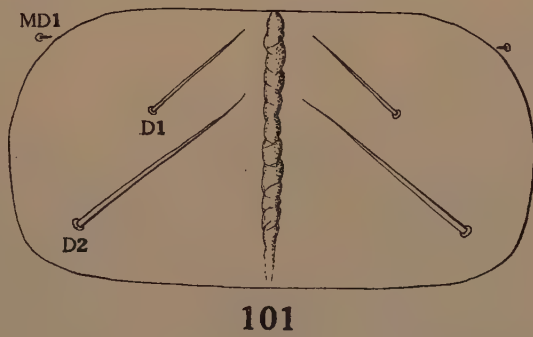
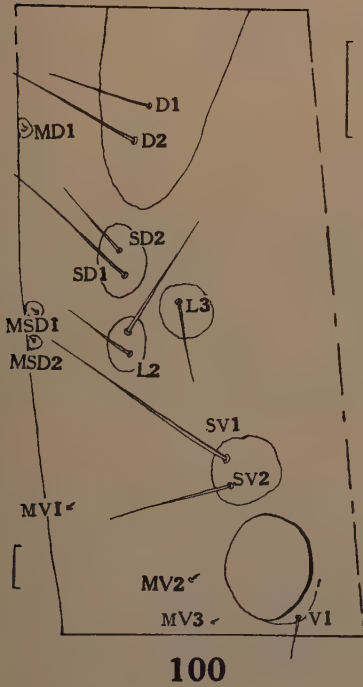
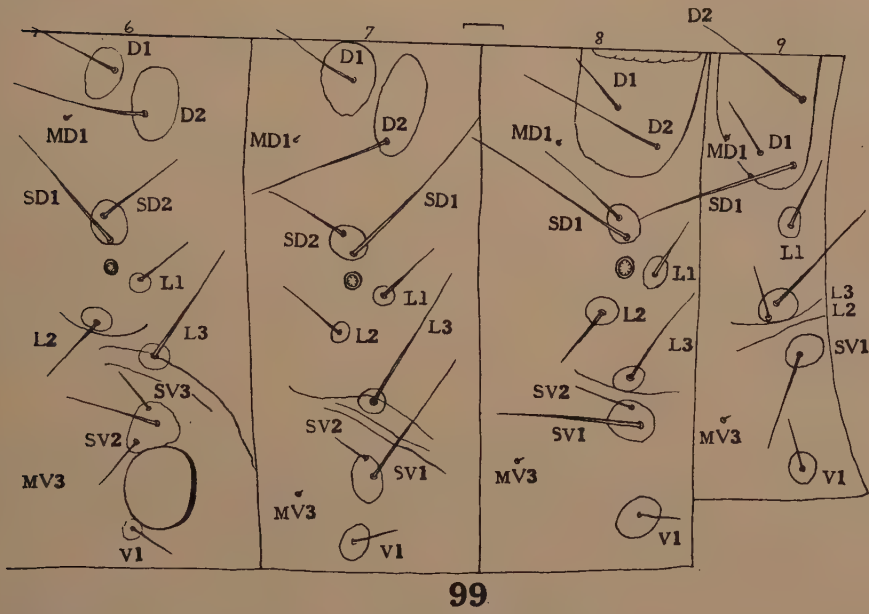
Mature larva. Length, 15-18 mm.; breadth, 2.5-3.0 mm. (estimate from shed cuticles of final-instar larva).

Head moderately dark brown with distinct but irregular, slightly darker patches; tergal and pleural plates of prothorax paler brown as are also tergum of mesothorax, mid-dorsal part of metathorax, and most of dorsum of ninth and



Figs. 94-98.—*Amydria vastella* (Zell.), mature larva. (94) Dorsal view of head. (95) Ventral view of left mandible. (96) Dorsal view of labrum. (97) Ocellar region of right side of head. (98) Dorsal and lateral setae of left side of prothorax.

tenth abdominal segments; legs and peritreme of spiracles brownish; cuticle elsewhere white or nearly so with pinnacula indistinct; surface of cuticle with dense, microscopic, pointed tubercles or microtrichia which are usually denser



Figs. 99-102.—*Amydria vastella* (Zell.), mature larva. (99) Setae of left side of sixth to ninth abdominal segments. (100) Mesothorax. (101) Dorsal carina of eighth abdominal segment and D and MD groups. (102) Dorsal view of tenth abdominal segment.

on "intersegmental" regions. Head (fig. 94) with part of fronto-clypeal apotome enclosed by adfrontal sutures behind and cleavage lines in front extending nearly three-fourths of distance to vertical triangle; antero-lateral part of each adfrontal area with a large gibbosity and a smaller and somewhat similar gibbosity in front of and slightly laterad from adfrontal gibbosity; with a single convex ocellar lens on each side near anterior margin. Coxae of all legs widely separated; pinnaculæ of V1 setae close to coxae but those of front legs fused to coxae. Abdomen with a median longitudinal carina on eighth tergite (fig. 101). Ventral prolegs with 32-36 crochets; posterior crochets about as large as anterior ones. Spiracles broadly oval; spiracles of eighth abdominal segment a fourth larger than those of seventh and four-fifths as large as those of prothorax. *Chaetotaxy* of head as shown in figs. 94 & 97. Prothorax (fig. 98) with SV group in a nearly horizontal line. Metathorax setose like mesothorax (fig. 100). Abdomen (fig. 99) with SV group of 1, 7, and 8 bisetose, of 2-6 trisetose, and of 9 unisetose.

Distribution. Africa.

Comparative notes. From all other species dealt with here, with the exception of "*Amydria* sp.", it may be immediately distinguished by its anterior adfrontal gibbosities and by having a median longitudinal carina on the eighth abdominal tergite. From "*Amydria* sp." it may be distinguished as shown under the heading of that species.

Habits. It has been found boring in the horns of water antelope, hartebeest, and other ruminants in various parts of Africa (Busck, 1910; McCorquodale, 1898; Seydel, 1938; Walsingham, 1881). According to Busck, horns of living ruminants may sometimes be attacked, but this requires confirmation. The species has also been recorded in dried fruit.

***Amydria* sp. (?)** (figs. 103-108).

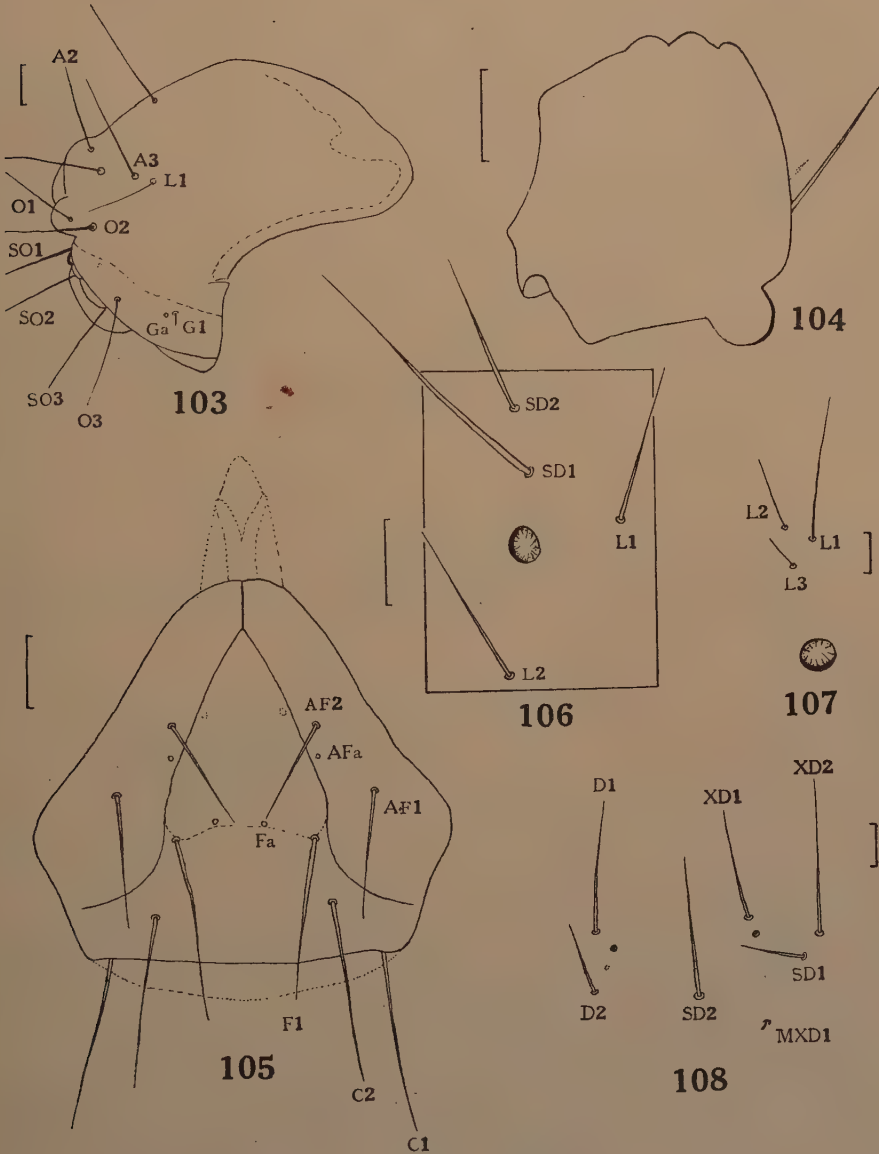
Mature larva. Externally similar to *A. vastella* (Zell.) from which it may be distinguished as follows: (1) D1 of ninth abdominal segment is nearly as close to D2 as to SD1. (2) The median longitudinal ridge of eighth abdominal tergite is narrow, knife-like, and strongly sclerotised instead of being broad and only feebly sclerotised. The edge of the ridge has broadly rounded crenulations. (3) The spiracles of the eighth abdominal segment are two-fifths instead of only a fourth larger than those of the seventh segment. And (4) SD1 of the prothorax is separated from XD2 by less than half the distance that separates XD1 from XD2 (fig. 108), instead of by distinctly more than half the distance between XD1 and XD2 (fig. 98).

***Trichophaga tapetzella* (Linnaeus) (1758)** (figs. 109-115, 119, 123).

Mature larva. Length, 9-11 mm.; breadth, 1.8-2.0 mm.

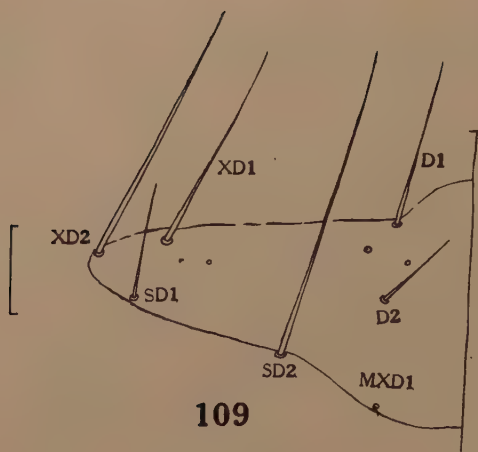
Head pale brown to moderately dark brown or yellowish brown with darker patches over the origins of the mandibular muscles; adfrontal areas, or both adfrontal areas and fronto-clypeus, usually darker; anterior, ventral, and occipital margins darker, often nearly black; each side above G group with a broad, longitudinal, black patch that extends from occipital margin nearly to L1. Tergal plates of prothorax pale brown or pale yellowish brown; parts of legs pale yellowish brown; peritreme of spiracles pale brown; cuticle elsewhere white or nearly white with pinnacula indistinct or not visible (mag. $\times 75$) except when cuticle is stained; surface of cuticle microscopically tuberculate as shown in fig. 123. Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending three-fourths of distance to vertical triangle; each side with a single

convex ocellar lens near anterior margin by SO2; surface densely, microscopically reticulate and with fine, irregular, indistinct, transverse rugae. Coxae of middle

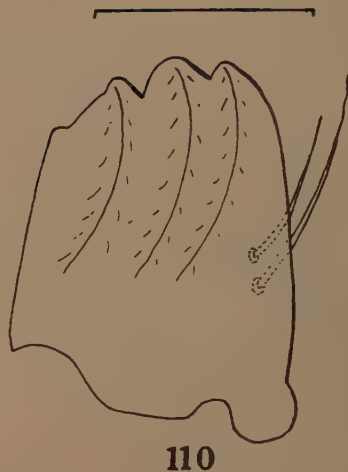


Figs. 103-108.—*Amydria* sp. from Zanzibar, mature larva. (103) Left side of head. (104) Ventral view of left mandible. (105) Fronto-clypeal apotome. (106) Spiracle of eighth abdominal segment and associated setae. (107) Spiracle and L group of prothorax. (108) Dorsal setae of left side of prothorax.

and hind legs widely separated, those of front legs moderately widely separated; pinnacula of V1 setae fused to coxae. Ventral prolegs (fig. 115) with 27-37 crochets; largest anterior crochets broader and longer than largest posterior



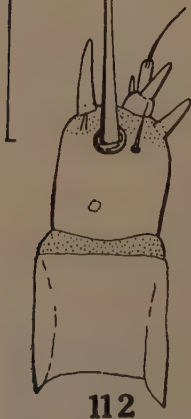
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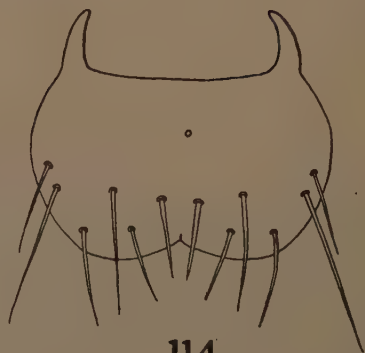
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114

Figs. 109-114.—*Trichophaga tapetzella* (L.), mature larva. (109) Dorsal setae of left side of prothorax. (110) Ventral view of left mandible. (111) Right side of prementum-hypopharynx. (112) Right antenna. (113) Ventral side of labrum. (114) Dorsal side of same.

crochets. Spiracles circular or very broadly oval; spiracles of eighth abdominal segment twice as large as those of seventh and about one-third larger than those of prothorax. *Chaetotaxy*. AF1 as far from AF2 as from F1 or slightly nearer the latter; AFa variable in position but usually distinctly nearer to AF1 than to AF2. V setae in a nearly straight line with V1 slightly further from V2 than from V3; Va nearly in a line between V2 and V3 and slightly nearer the latter. P1 slightly before level of AF1 and P2 slightly laterad from it and about at level of AF2; Pb very variable in position, usually postero-mesad from P2; Pa almost directly laterad from P1 and widely separated from it. Aa laterad from and slightly in front of A2. L1 laterad from A3 and nearly as far behind as P2. O3 slightly nearer Ga than O2 and latter very slightly nearer O3 than O1. SO group forming a nearly equilateral triangle but SO3 slightly nearer SO2 than is SO1. Ga antero-dorsad from G1. Prothorax with L2 and L3 in a nearly horizontal line and L1 between and below them; with a puncture behind L1; SV group in a nearly horizontal line. Meso- and metathorax setose like *Monopis rusticella* (Clerck) (fig. 132) but with MSD setae on separate pinnacula. Abdomen with SD group and L1 and L2 as shown in fig. 119; SV group of 1, 7, and 8 bisetose, of 2-6 trisetose, and of 9 unisetose; all SV setae of abdomen on separate pinnacula; ninth segment with D1 as far from D2 as from SD1 but usually with its pinnaculum fused to that of D2; D2 of right and left sides on same pinnaculum.

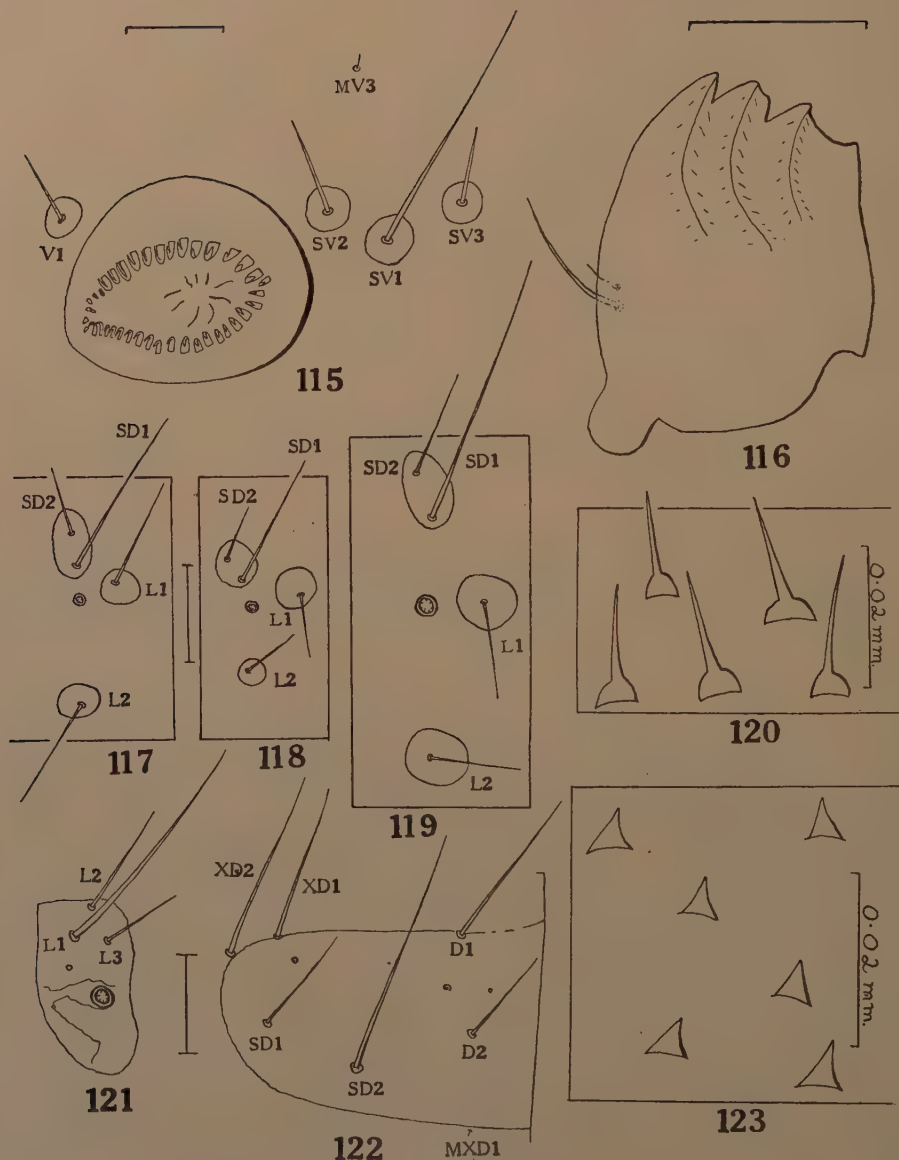
Distribution. Cosmopolitan.

Comparative notes. The species of *Trichophaga* closely resemble the species of *Monopis* from which they may be distinguished as shown in the key. *T. tapetzella* differs from *T. swinhoi* (Butler) in having the distal seta of the mandible more than half as long as the proximal instead of much less than half as long.

Habits. The larva feeds on hair, wool, and feathers or on materials containing these. It is more common in outhouses and stables than in houses, perhaps because houses tend to be too dry for it. It is chiefly a pest in temperate regions, and in tropical countries it is largely or entirely replaced by other species of *Trichophaga*, especially *T. abruptella* (Woll.), as noted by Fletcher (1916). In the field, it is reported from owl casts in Europe (Baer, 1924) and North America (Forbes, 1923), and it is sometimes found feeding on the fur of dead animals. It has been found in Britain attacking rabbit skins out-of-doors (Laing, 1932). In California, it has been found in the nests of *Scelophoron* (Linsley, 1944). In Britain it has been found in barns and granaries (Fryer, 1932), in stored bird guano (Hinton & Greenslade, 1943), and has often been reported in stables attacking the hair stuffing of saddles and collars (*e.g.*, Fryer, 1932; Ford, 1931). Other records are: on opossum skins in New Zealand, rabbit skins in Hawaii (Jensen, 1945), and furs and blankets in Switzerland (Patton, 1931). Notes on its life-history and habits are given by Adkin (1923), Anon. (1941), Back (1935), Bruneteau (1930), Curtis (1932), Doner & Thomssen (1943), Kemper (1934, 1935), Lesser (1949), Marlatt (1915), Ossipov (1915), Patton (1931), and Zacher (1927). Methods of trapping adults and larvae by using fish-meal, cod-liver oil, and other substances as lures are given by Wilson (1940). The only parasite recorded from it appears to be *Apanteles carpatus* (Say) (Ferrière, 1941; Muesebeck, 1920).

***Trichophaga swinhoi* (Butler) (1884) (fig. 116).**

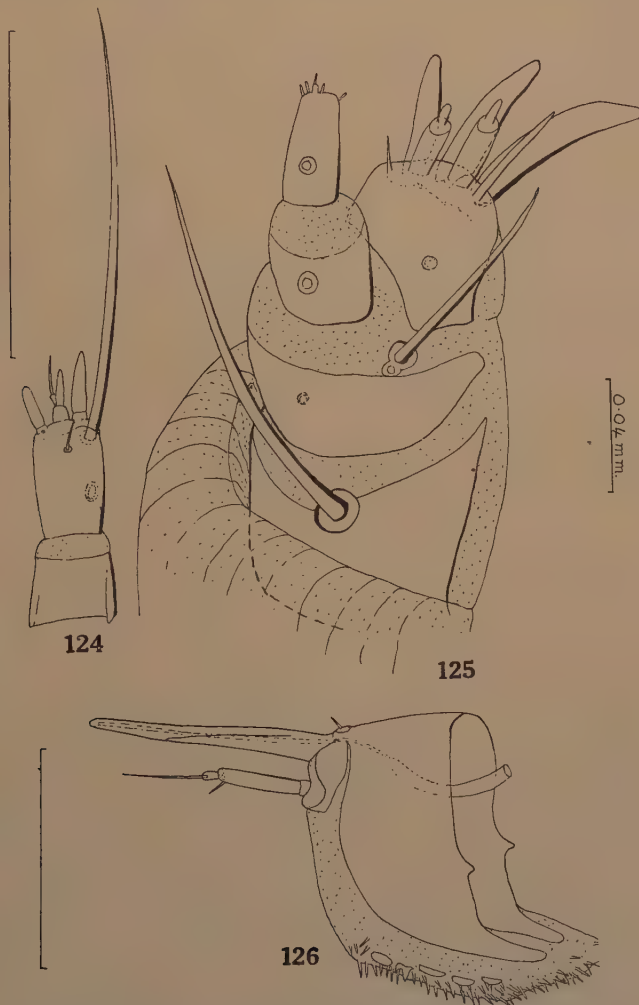
Mature larva. Very similar to *T. tapetzella* (L.) but with the distal seta of the mandible (fig. 116) very much less than half as long as the proximal instead of distinctly more than half as long (fig. 110).



Figs. 115-123.—(115) Left proleg of fourth abdominal segment of mature larva of *Trichophaga tapetzella* (L.). (116) Ventral view of right mandible of mature larva of *Trichophaga swinhoei* (Butler). (117) Spiracle and associated setae of left side of seventh abdominal segment of mature larva of *Monopis rusticella* (Clerck). (118) Same of *M. ferruginella* (Hübner). (119) Same of *Trichophaga tapetzella*. (120) Microtrichia of the eighth abdominal tergite of *Monopis ferruginella*. (121) Spiracle and L group of prothorax of mature larva of *Monopis congestella* (Walk.). (122) Dorsal setae of left side of prothorax of same. (123) Microtrichia of the eighth abdominal segment of the mature larva of *Trichophaga tapetzella*.

Only the shed cuticle of one final-instar larva has been examined. AFa is nearly contiguous to AF1, but as AFa is very variable in position in *T. tapetzella*, this feature may prove to be of no importance in distinguishing the two species.

Distribution. Africa, Arabia.



Figs. 124-126.—*Monopis rusticella* (Clerck), mature larva.
(124) Antenna. (125) Ventral view of right maxilla.
(126) Right side of prementum-hypopharynx.

Habits. The larva has been found in dog's dung in Aden (de Joannis, 1899), in camel's dung in Obock (Walsingham & Hampson, 1896), and in jackal's dung in Helmieh (Alfieri, 1914). The larvae examined by me were taken in hyaena's dung in Kenya.

***Monopis rusticella* (Clerck) (1759) (figs. 117, 124-139).**

Mature larva. Length, 9-11 mm.; breadth, 1.5-2.0 mm.

Head moderately pale to moderately dark brown or reddish brown; adfrontal areas, or both adfrontal areas and fronto-clypeus, usually darker; anterior, ventral,

and posterior margin darker brown, often nearly black; each side above G group and at level of O2 with a broad, longitudinal, dark brown to black stripe that extends from occipital margin as far forwards as O3 and sometimes nearly reaches O2; tergal plates of prothorax pale brown; pleural plates of prothorax and tergal plate of tenth abdominal segment paler brown; peritreme of spiracles and parts of legs yellowish brown; cuticle elsewhere white or nearly white with indistinct pinnacula (pinnacula very distinct in stained specimens); surface of cuticle with dense microtrichia as in *M. ferruginella* (fig. 120). Head (fig. 129) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending about three-fourths of distance to vertical triangle; each side with a single convex ocellar lens near anterior margin by SO2; surface densely, microscopically reticulate in parts to sparsely, microscopically punctate in other parts, especially posteriorly, and with sparse, fine, irregular, transverse rugae. Coxae of all legs widely separated; pinnacula of V1 setae completely fused to coxae. Ventral prolegs (fig. 138) usually with 22–25 crochets; anterior crochets much broader and distinctly longer than posterior; ellipse of crochets narrowly open on mesal side, but this only evident when proleg is fully evaginated. Spiracles circular or nearly so; spiracles of eighth abdominal segment twice as broad as those of seventh and nearly a third broader than those of prothorax. *Chaetotaxy*. Cranial setae and sensory pores as shown in figs. 129–130. Prothorax (figs. 136–137) with SV group in a nearly horizontal line and on the same pinnaculum. Metathorax setose like mesothorax (fig. 132). Abdomen (figs. 117, 133–135, 139) with SV group of 1 and 7 bisetose, of 2–6 trisetose (fig. 138), and of 8–9 unisetose; ninth segment with D1 on same pinnaculum as SD1 and much closer to it than to D2.

Distribution. Europe, Asia, North America.

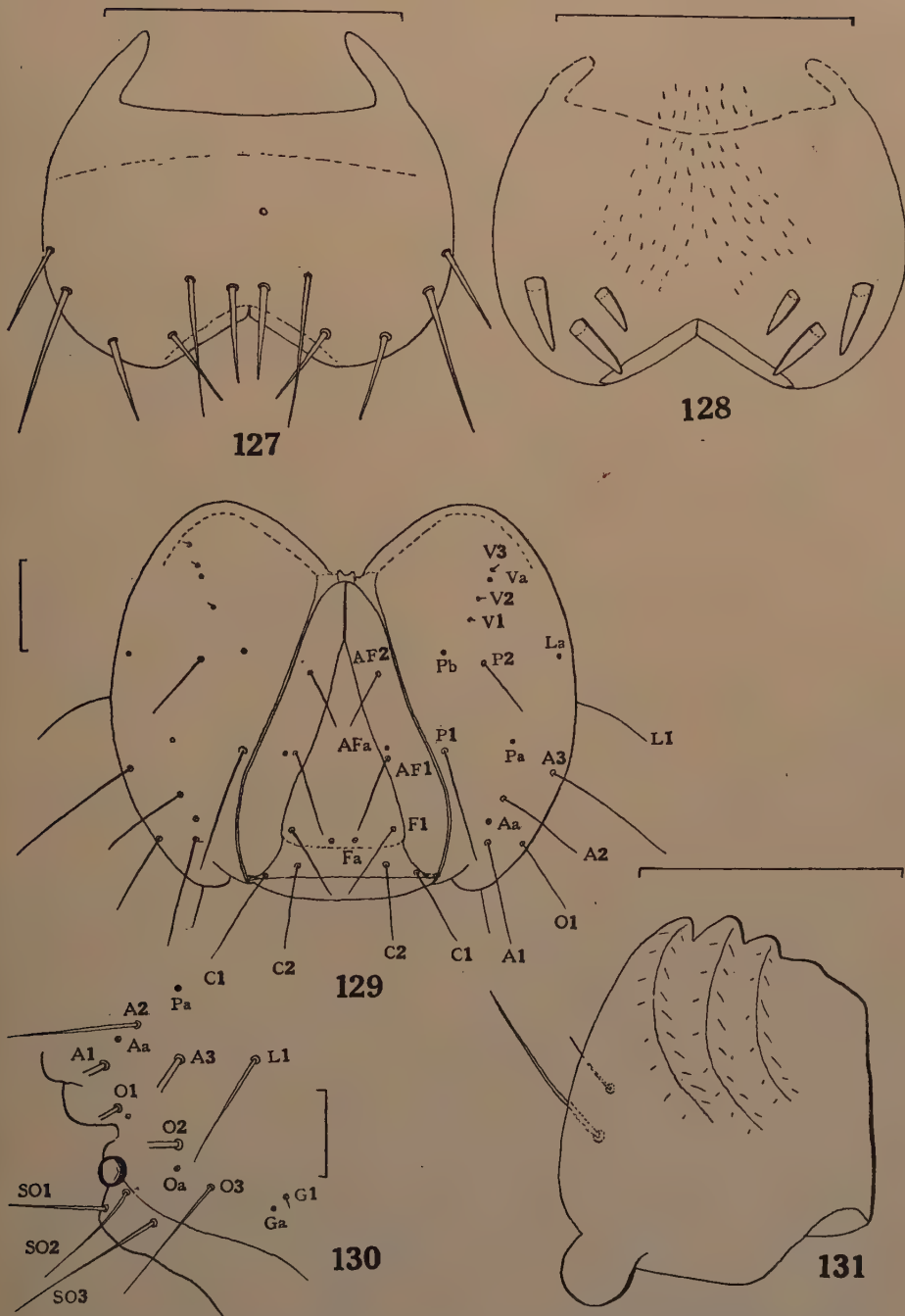
Comparative notes. From the other species of *Monopis* described here it may be distinguished by having the SV group of the eighth abdominal segment unisetose instead of bisetose.

Habits. In Britain I have found this more frequently than any other Tineid in owl casts. Others have also found it in owl casts, e.g. Buxton (1914) and Nurse (1906). It has been found breeding in the fur of a dead cat (Eales, 1872), and larvae have been found by me on dead rabbits and dead crows. It is common in bird nests (Fletcher in Bankes, 1910; Schütze, 1931; Waters, 1928; Woodroffe & Southgate, 1951a; Woodroffe, 1953). Larvae have been frequently found by me in the nests of thrushes, hedge-sparrows, and other birds in Cambridgeshire, and it has been bred by Mr. E. B. Basden from the nests of chaffinch, hedge-sparrow, house-sparrow, greenfinch, stonechat, great tit, linnet, sand-martin, barn-owl, blackbird, and carrion crow. It is common in outhouses and stables (e.g., Ford, 1931) and is sometimes found in houses (Fletcher in Bankes, 1910; Lack, 1932; Schütze, 1931; Waters, 1928). It has been found breeding in stored bird guano (Hinton & Greenslade, 1943) and in a rotten carpet (Sich, 1909a). Other notes on its biology are given by Adkin (1923). *Ephialtes extensor* Taschb. is recorded as a parasite (Seyrig, 1924) and possibly *Hemiteles floricator* Grav. (Morley & Rait-Smith, 1933). *Phygadeuon rusticellae* Bridgm. has been recorded as a parasite, but it is a parasite of Diptera (Basden in Richards, 1949).

***Monopis ferruginella* (Hübner) (1810–13) (figs. 118, 120, 140–146).**

Mature larva. Length, 6.0–7.5 mm.; breadth, 1.2–1.5 mm.

Similar in appearance and colour to a small *M. rusticella* but lateral dark brown or black stripe of head is narrower, more parallel-sided, and usually extends up to O2 and often slightly beyond. Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending nearly three-fourths of distance to vertical triangle; each side with a single convex ocellar lens near anterior



Figs. 127-131.—*Monopis rusticella* (Clerck), mature larva. (127) Dorsal surface of labrum. (128) Ventral view of labrum. (129) Dorsal view of head. (130) Ocellar region of left side of head. Drawn from a somewhat flattened cast cuticle. (131) Ventral view of right mandible.

margin by SO₂; surface moderately sparsely, microscopically punctate and with fine, indistinct, irregular, transverse rugae. Coxae moderately widely separated; pinnacula of V₁ setae completely fused to coxae. Ventral prolegs (fig. 144) usually with 18–20 crochets; anterior crochets much longer and broader than posterior; ellipse of crochets narrowly open on mesal side, but this only evident when prolegs are fully evaginated. Spiracles circular to broadly oval; spiracles of eighth abdominal segment twice as broad as those of seventh and about a third broader than those of prothorax. *Chaetotaxy*. AF₁ nearer to AF₂ than F₁; AF_a usually slightly nearer AF₁. V₁ nearer V₂ than is V₃; V_a nearly in a straight line between V₂ and V₃, and nearer to latter than to former. P₁ directly laterad from AF₁; P₂ postero-laterad from P₁ and nearly or quite as far back as AF₂; P_b postero-mesad from P₂ and nearer to latter than to V₁; P_a almost directly laterad from P₁. A_a in a straight line between A₁ and A₂ or slightly laterad from these but distinctly nearer to A₂. L₁ behind and slightly below A₃, nearer to latter than to O₂; L_a nearly directly behind L₁. O₂ slightly nearer to O₃ than to O₁; O_a antero-dorsad from O₃. SO group forming a nearly equilateral triangle with SO₂ slightly nearer SO₁ than is SO₃; SO_a usually ventrad from and near to SO₂. G_a in front of and slightly above G₁. Prothorax (fig. 143) with SV group in a nearly horizontal line and on the same pinnaculum. Mesothorax with both D setae on the same pinnaculum with D₂ slightly in front of D₁; SD setae on the same pinnaculum and in a vertical line. L setae on separate pinnacula; L₃ above and behind L₁; L₂ below and slightly in front of L₁; SV setae on same pinnaculum and in a vertical line; MD₁ in front of D₂, without a distinct pinnaculum; MSD setae on same pinnaculum with MSD₂ below and in front of MSD₁. Metathorax setose like mesothorax. Abdomen (figs. 118, 120, 140–141, 145) with SV group of 1, 7, and 8 bisetose, of 2–6 trisetose, and of 9 unisetose; SV setae always on same pinnaculum where more than one is present; ninth segment with D₁ on same pinnaculum as SD₁ and nearer to latter than to D₂.

Distribution. Europe, Asia, North Africa.

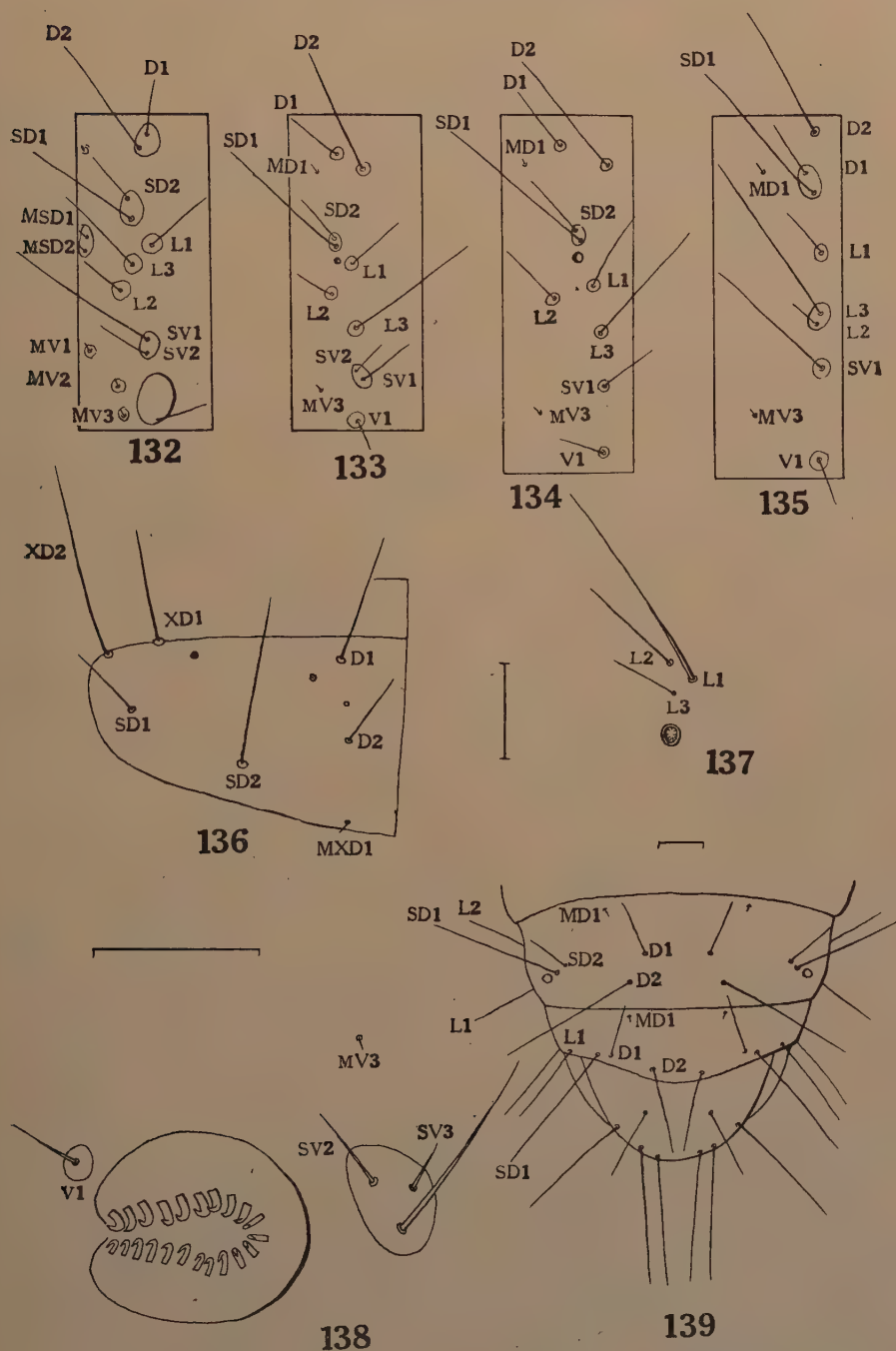
Comparative notes. It may be distinguished from *M. rusticella* (Clerck) by having the SV group of the eighth abdominal segment bi- instead of unisetose. From *M. congestella* (Walker) it differs as shown under the heading of that species.

Habits. The larvae have frequently been found by me in woollen materials left out-of-doors in Cambridgeshire and at both Oxshott and Ashted in Surrey. Larvae have also been found by me in owl casts and adults in houses. It has been bred from the nest of a blackbird (E. B. Basden, personal communication) and is common about outhouses (Pyett, 1903) and stables (Ford, 1931), and there are several records of its occurrence in houses (e.g., Machin, 1870; Pyett, 1898; and Schütze, 1931). A parasite, *Phygadeuon bitinctus* (Grav.), has been bred from a mixed culture of this species and *Acedes semifulvella* (Haw.) (Hinton in Richards, 1949).

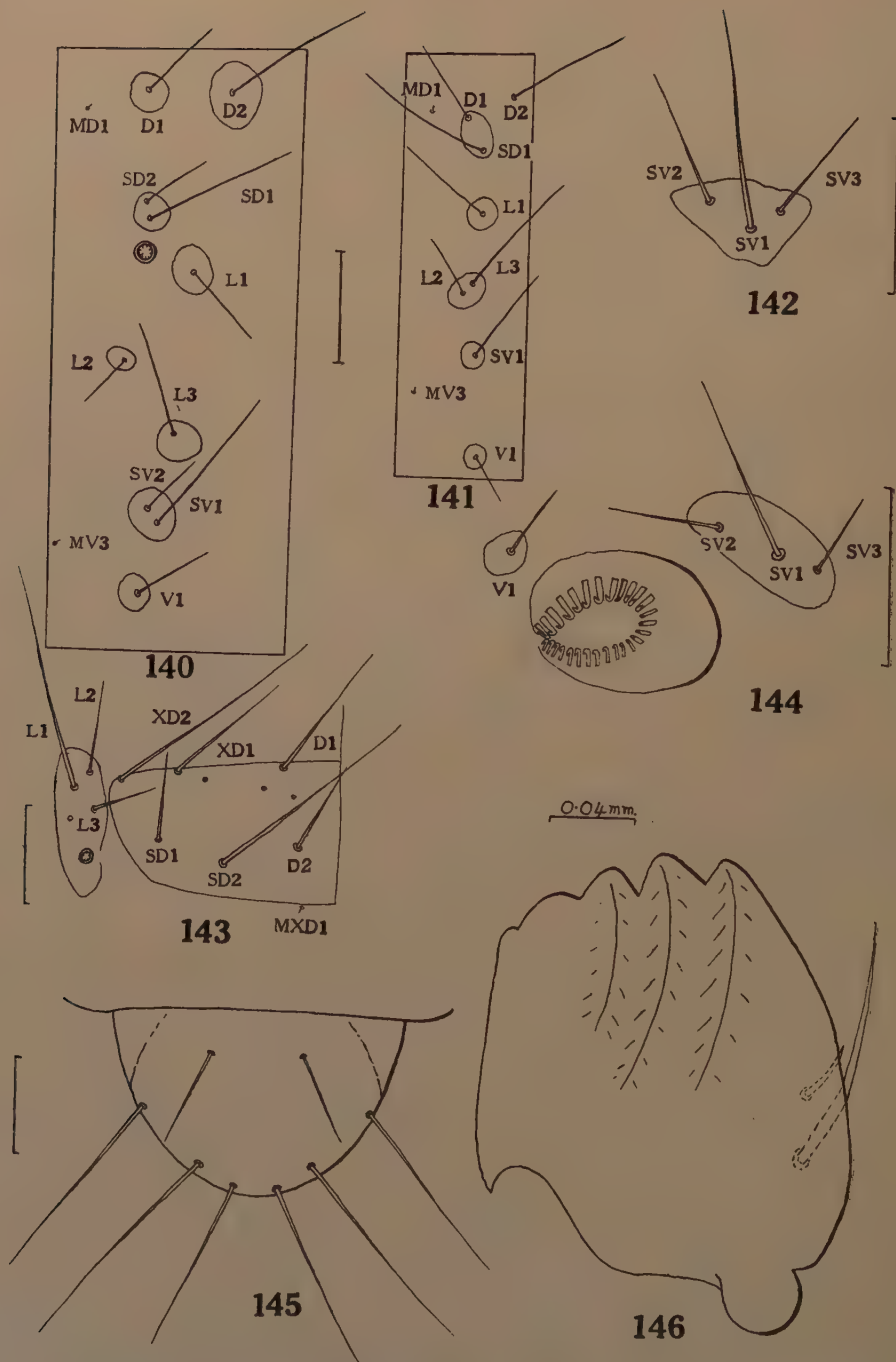
***Monopis congestella* (Walker) (1864) (figs. 121–122).**

Mature larva. Similar in size and structure to *M. ferruginella* (Hübner). It differs in having on each lobe of the hypopharynx six or seven large sclerotised plates arranged in a longitudinal line. These plates are amongst the usual slender cuticular processes. *M. ferruginella* lacks such plates, the general appearance of which may be seen in the figure of the hypopharynx of *M. rusticella* (Clerck) (fig. 126). The dark brown or black stripe on the head is similar to that of *M. rusticella*, and, as in that species, it does not extend as far as seta O₂.

Only a single shed cuticle of a final-instar larva has been examined.



Figs. 132-139.—*Monopis rusticella* (Clerck), mature larva. (132) Mesothorax. (133) Seventh abdominal segment. (134) Eighth abdominal segment. (135) Ninth abdominal segment. (136) Dorsal setae of left side of prothorax. (137) Spiracle and L group of right side of prothorax. (138) Right proleg of third abdominal segment. (139) Dorsal view of eighth to tenth abdominal segments.



Figs. 140-146.—*Monopis ferruginella* (Hübner), mature larva. (140) Eighth abdominal segment. (141) Ninth abdominal segment. (142) SV group of fifth abdominal segment. (143) Dorsal and lateral setae of left side of prothorax. (144) Left proleg of third abdominal segment. (145) Dorsal view of tenth abdominal segment. (146) Ventral view of left mandible.

Distribution. Sarawak, New Hanover.

Habits. The specimen described was bred from stored *Sexava* eggs.

***Tinea pellionella* (Linnaeus) (1758) (figs. 147-160).**

Mature larva. Length, 6.5-8.5 mm.; breadth, 1.5-1.9 mm.

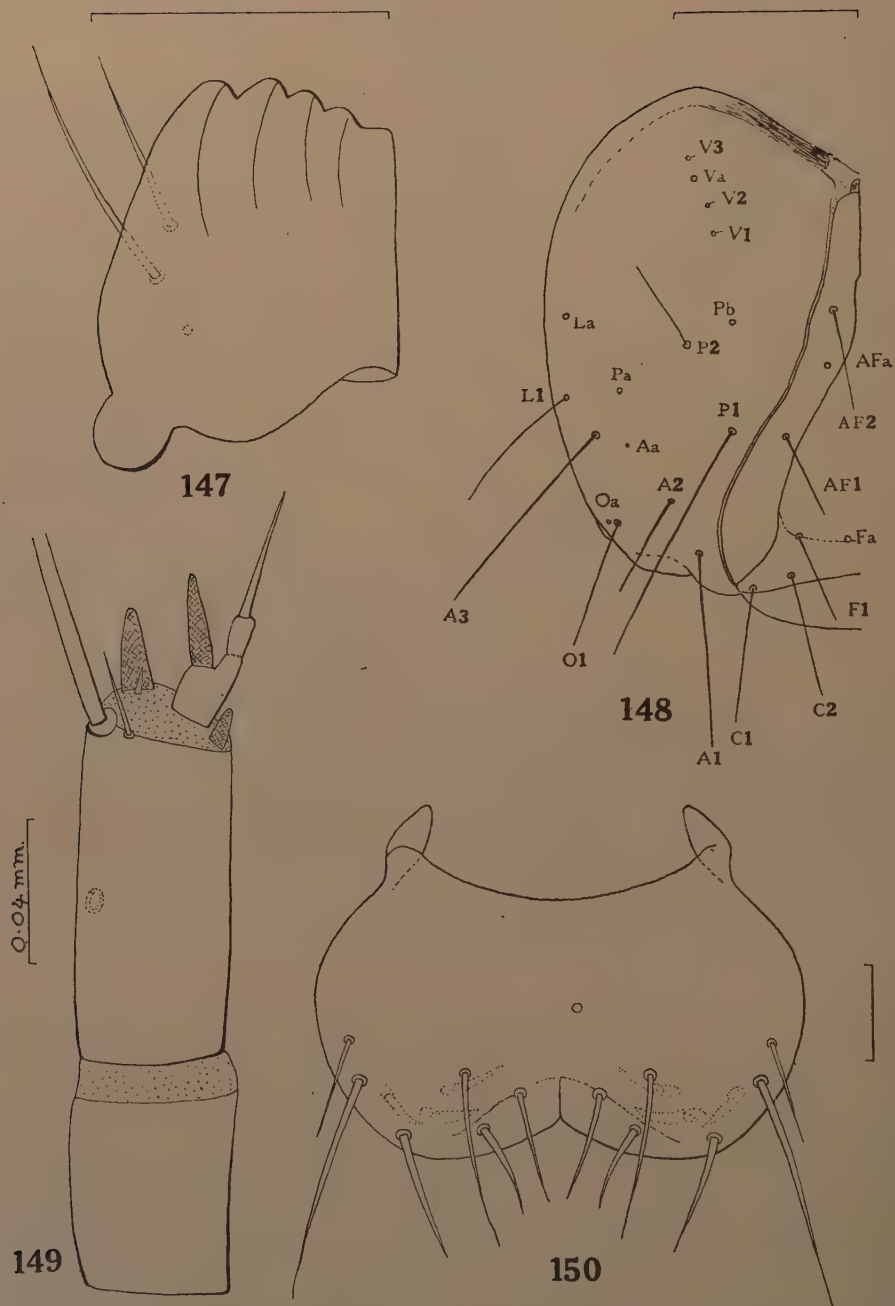
Head moderately dark or very dark brown with anterior margin, ventral margin, and often adfrontal areas distinctly darker; each side with or without a narrow dark stripe at level of O2 extending from occipital margin nearly as far, or as far, as O2; prothorax with tergal and pleural plates as dark or nearly as dark as head but without tinge of red of latter; parts of dorsal surface of legs pale brownish; peritreme of spiracles paler brown; cuticle white or nearly white with pinnacula not or only scarcely visible; surface of cuticle (fig. 160) densely, microscopically tuberculate with feebly convex, nearly flat-topped tubercles. Head (fig. 148) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending slightly more than three-fourths of distance to vertical triangle; each side with a single convex ocellar lens near anterior margin by SO2; surface densely, microscopically reticulate but more sparsely reticulate or microscopically punctate posteriorly and with fine, sparse, irregular, transverse rugae. Coxae of middle and hind legs widely separated and coxae of front legs only about half as widely separated as those of middle legs; pinnacula of V1 setae completely fused to coxae. Ventral prolegs usually with 28-32 crochets; anterior crochets at least a third broader and longer than posterior ones; ellipse of crochets narrowly but evidently open on mesal side when proleg is fully evaginated. Spiracles circular to very broadly oval; spiracles of eighth abdominal segment about twice as broad as those of seventh and at least a third broader than those of prothorax. *Chaetotaxy.* Cranial setae as shown in fig. 148; position of Aa somewhat variable but always unusual in that it is far behind A2 and usually closer to A3 than to A2. O2 about half again as far from O1 as from O3, and distinctly nearer to latter than to L1 or A3; Oa in front of O3 and between the latter and O2; each side with a puncture slightly laterad from O1, which is apparently not the homologue of Oa of other species. SO group forming an approximately equilateral triangle; SOa between SO2 and SO3. Ga before and slightly above G1. Prothorax (fig. 157) with SV group in a nearly vertical line and on the same pinnaculum. Metathorax setose like mesothorax (fig. 153). Abdomen (figs. 154-156, 158) with SV group of 1, 7, and 8 bisetose, of 2-6 trisetose, and of 9 unisetose; ninth segment with pinnaculum of D1 more or less completely fused to that of SD1, very rarely separate; D1 of ninth slightly but distinctly nearer to SD1 than to D2.

Distribution. Cosmopolitan.

Comparative notes. The larva is always in a fusiform, dorso-ventrally flattened, portable case that has an opening flap at both ends. It pupates in the larval case. It is very closely related to *T. columbariella* Wocke, from which it may be distinguished as shown under the heading of that species.

Habits. The larva is most frequently found feeding on keratin-containing substances such as hair, fur, and feathers or on materials containing these. Of the TINEIDAE attacking furs and woollens in Europe and most other temperate parts of the world it is second in importance only to *Tineola bisselliella* (Humm.).

In Europe, it is common in bird nests, e.g. domestic pigeon, stock-dove (*Columba oenas*), house-sparrow, redstart, woodpecker (*Dryobates major*), starling, and jackdaw in Finland (Nordberg, 1936), house-martin in Germany (Otten, 1941), hedge-sparrow (Waters, 1928) and house-sparrow, starling, robin, and pied wagtail in England (Woodroffe & Southgate, 1951a), and it has been found by me in large numbers in nests of swallows and house-sparrows in various parts of

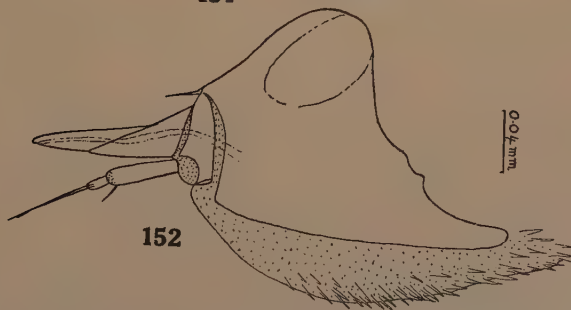


Figs. 147-150.—*Tinea pellionella* (L.), mature larva. (147) Ventral view of right mandible. (148) Dorsal view of right side of head. (149) Antenna. (150) Dorsal view of labrum.

England. It is said to feed on cobwebs (Davids, 1869), and I have found it feeding on the remains of a *Tegenaria* beneath a web in a shed. It has been found in owl pellets in France (de Joannis, 1899). It has been found in stored bird guano (Hinton & Greenslade, 1943), and Walsh (1929) records the larva feeding on stored *Aconitum* root, Cayenne pepper, horse-radish, *Strophanthus*



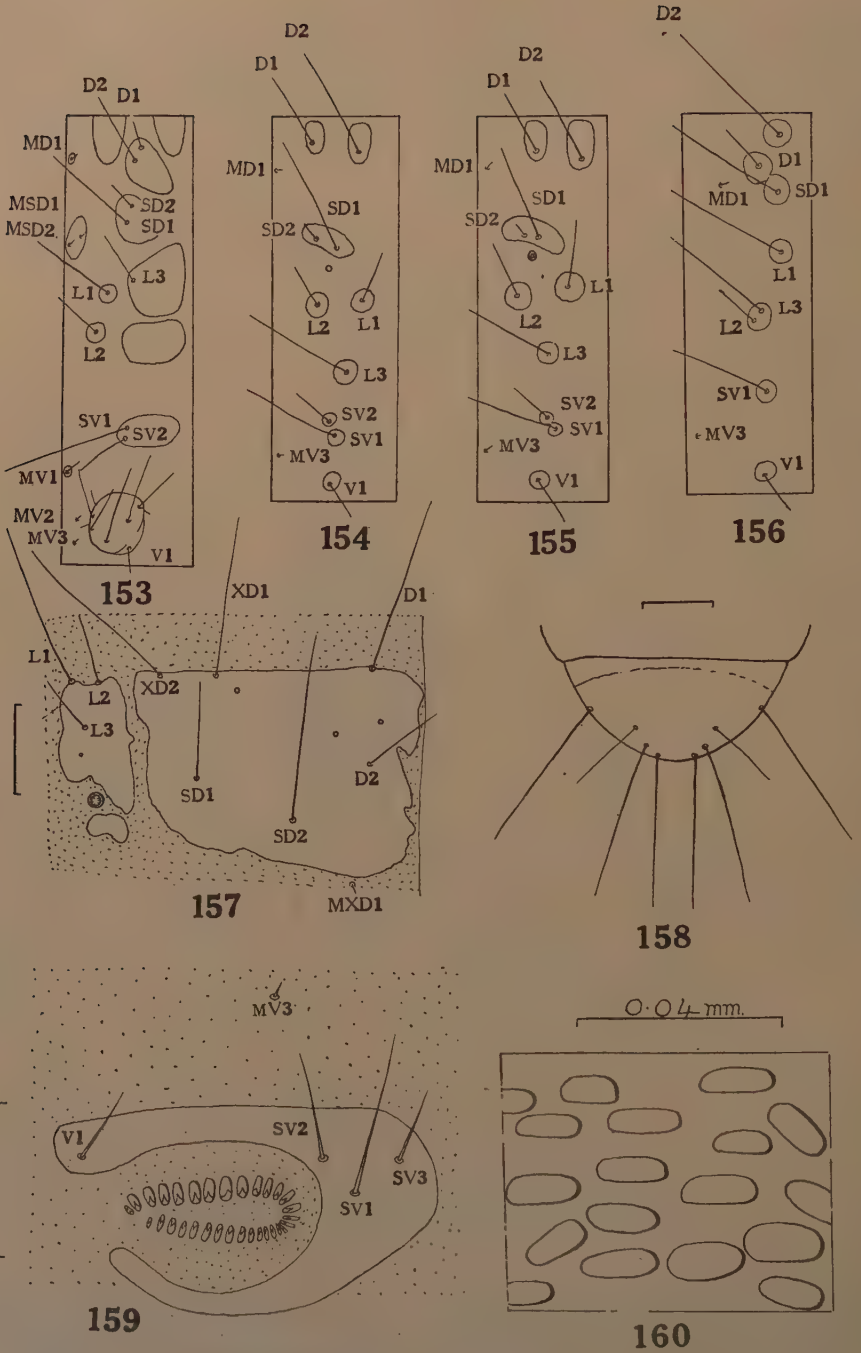
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152

Figs. 151-152.—*Tinea pellionella* (L.), mature larva.
(151) Ventral view of right maxilla. (152) Right side
of prementum-hypopharynx.

(used as an arrow poison in East Africa), common hemp, cherry-laurel leaf, black mustard seed, ginger, orris root, poppy capsules, linseed, almonds, saffron, and a monkey's skin used as a bag for bitter aloes. It has been reported as a pest of stored tobacco (Zacher, 1917), and it sometimes damages zoological collections (Pliginskii, 1915). It has been recorded doing serious damage to wool and mohair fleeces in the United States (Back, 1946). The susceptibility of various animal fibres to its attack is discussed by Burgess & Poole (1931).



Figs. 153-160.—*Tinea pellionella* (L.), mature larva. (153) Mesothorax. (154) Seventh abdominal segment. (155) Eighth abdominal segment. (156) Ninth abdominal segment. (157) Dorsal and lateral setae of left side of prothorax. (158) Dorsal view of tenth abdominal segment. (159) Right proleg of fourth abdominal segment. (160) Microsculpture of cuticle of eighth abdominal segment.

An account of the construction of the larval case is given by Yamada (1940). Methods of mass rearing for experimental purposes are described by Griswold (1934, 1944). Its habits and life-history have been frequently described (Anon., 1941, 1943; Back, 1935, 1939; Back & Cotton, 1930, 1931; Bruneteau, 1930; Doner & Thomssen, 1943; Fletcher, 1920; Griswold, 1944; Jenkins, 1944; Kemper, 1934, 1935; Lesser, 1949; Linsley, 1946; Miller, 1948; Ossipov, 1915; Patton, 1931; Spencer, 1931; Zacher, 1927), but it appears that no really comprehensive account of its life-history has yet been published. The recent paper by Cheema (1956) should be seen for the effects of temperature and relative humidity on the duration of the various stages. The surface structure of its eggs and those of other clothes moths is described by Pappenheim (1938).

The following parasites have been recorded from it: *Hemiteles cinctus* (L.) (Richards, 1949), *Hypsicera mansuetor* (Grav.) (referred to as *Metacoelus mansuetor* (Grav.)) (Marlatt, 1915; Morley, 1930; Richards, 1949), *Apanteles carpatus* (Say) (referred to as *A. igae* Watanabe) (Watanabe, 1932), *A. rio-grandensis* Brèthes (Brèthes, 1920), *A. carpatus* (Say) (Burks, 1943; Ferrière, 1941; Marlatt, 1915), *Chremylus rubiginosus* (Nees) (Mason, 1948; Morley & Rait-Smith, 1933), and *Chremylus claphus* Hal. (referred to as *Paramesocrina tineavora* Nagamori) (Nagamori, 1925).

***Tinea columbariella* Wocke (1877) (fig. 161).**

Mature larva. Similar in colour, size, and external structure to *T. pellionella* (L.), but differs in not having a convex ocellar lens on each side of the head.

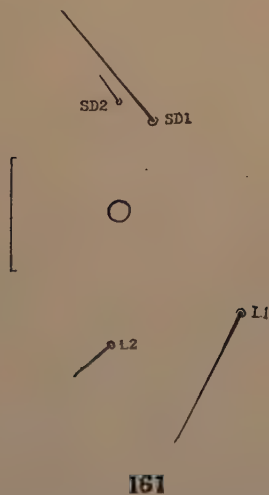


Fig. 161.—*Tinea columbariella* Wocke, mature larva. Spiracle and associated setae of left side of fourth abdominal segment.

The larva, like that of *T. pellionella*, has a fusiform, dorso-ventrally flattened, portable case with an opening flap at both ends. It pupates in the larval case.

Distribution. Europe, North America.

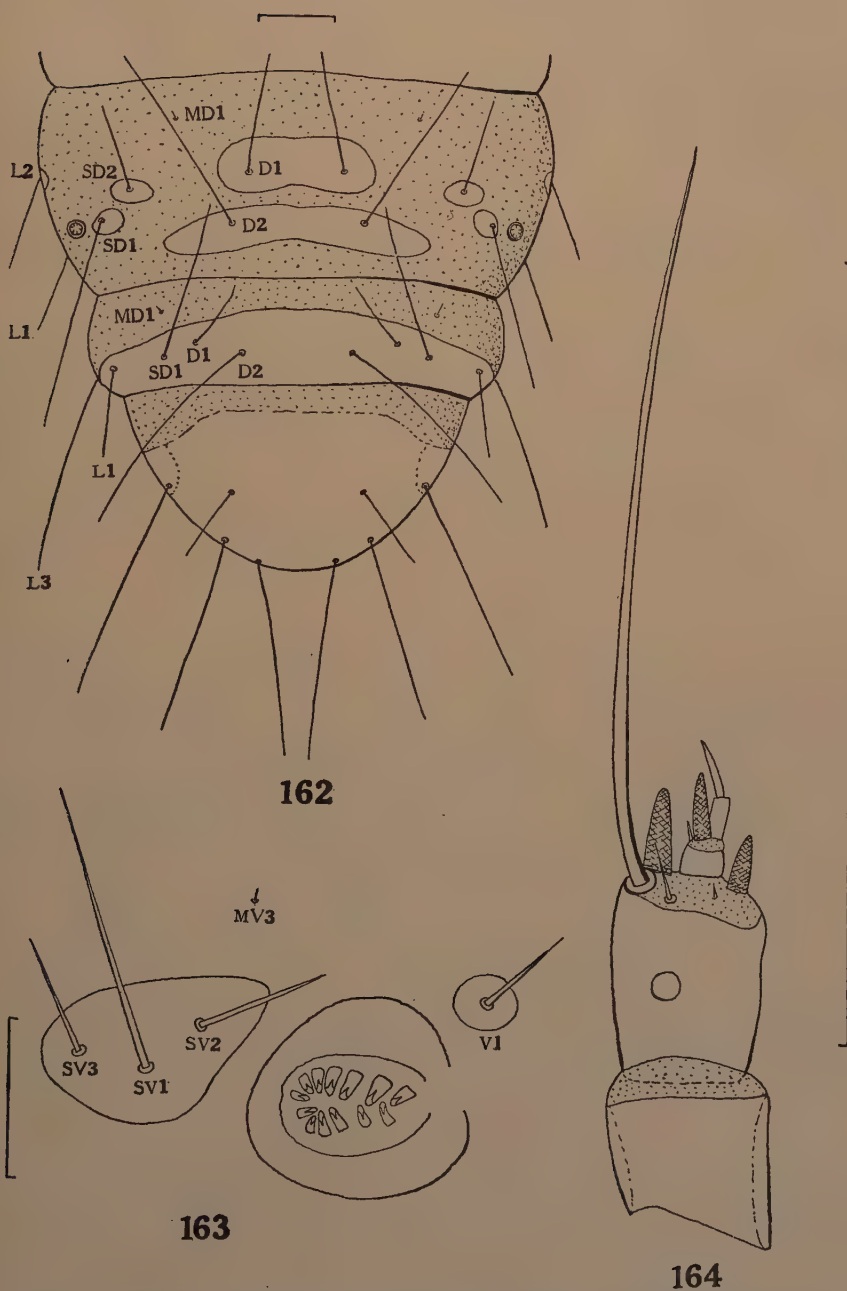
Habits. It is common in bird nests in Europe (Spuler, 1910). It has been found in the nests of house-sparrow, starling, jackdaw, robin, pied wagtail, and

swallow in England (Woodroffe & Southgate, 1951a; Woodroffe, 1953) and in pigeon-cotes, fowl houses, and swallow nests in Germany (Schütze, 1931). It has been found infesting woollen clothing in houses in England (Woodroffe, 1950), and it sometimes with other insects causes serious damage to wool and mohair fleeces in the United States (Back, 1946). The surface sculpture of its egg has been described by Pappenheim (1938), and the adult has recently been re-described and illustrated by Bradley (1950). *Apanteles carpatus* (Say) (Woodroffe & Southgate, 1951b), *Hypsicera mansuetor* (Grav.) (referred to as *Metacoelus mansuetor* (Grav.)) and *Dibrachys cavus* (Walker) are recorded as parasites (Woodroffe, 1953). The larva of *Scenopinus fenestralis* (L.) preys upon the larva (Woodroffe, 1953).

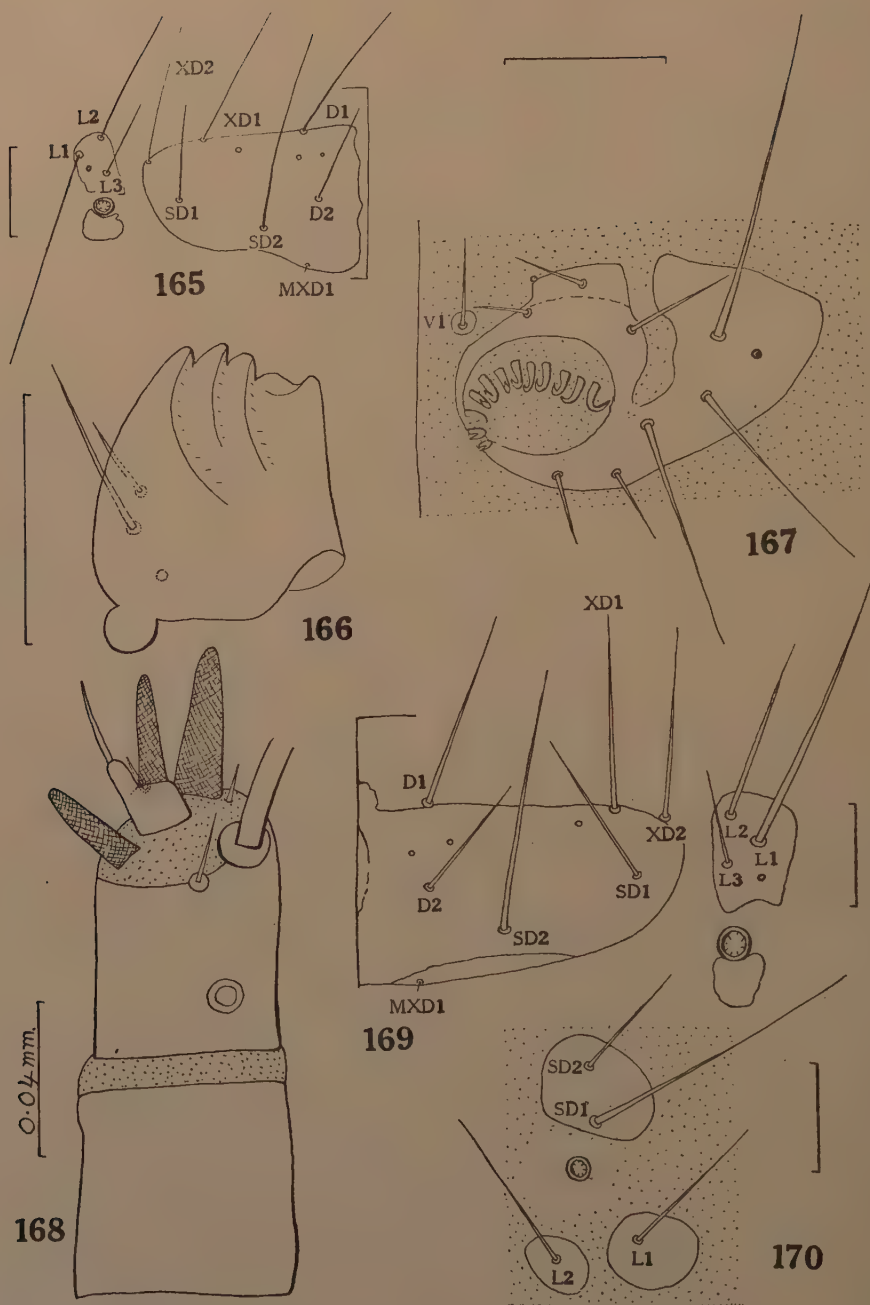
***Acedes ganomella* (Treitschke) (1833) (figs. 162–167).**

Mature larva. Length, 7·0–8·5 mm.; breadth, 1·2–1·6 mm.

Head moderately pale yellowish brown with adfrontal areas and anterior margin usually distinctly darker; occipital margin, parts of meso-ventral margin, and hypostomal suture black or nearly black; each side with a broad longitudinal, black or nearly black stripe at level of ocellus extending from occipital margin to or slightly beyond seta O2; tergal and pleural plates of prothorax and tergal plate of tenth abdominal segment usually distinctly darker brown than head and less yellowish; parts of legs and posterior and lateral parts of middle region of tenth abdominal prolegs paler brown; peritreme of spiracles pale brown; cuticle elsewhere white or nearly white with pinnacula more or less indistinct; surface of cuticle with dense, slender, pointed, microtrichia, each of which arises from a fine tubercle. Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending three-fourths of distance to vertical triangle; each side with a single convex ocellar lens near anterior margin between SO2 and O1; surface of head rather indistinctly but densely and microscopically reticulate or punctate, this microsculpture sparser posteriorly; surface also with numerous fine, indistinct, irregular but usually more or less transverse rugae. Coxae of middle and hind legs widely separated; coxae of front legs about three-fifths as widely separated as those of middle legs; pinnacula of V1 setae completely fused to coxae. Ventral prolegs (fig. 163) usually with 13–15 crochets; anterior crochets much broader and longer than posterior; ellipse of crochets narrowly open on mesal side when proleg is fully evaginated. Spiracles circular; spiracles of eighth abdominal segment twice as broad as those of seventh and about a fourth broader than those of prothorax. *Chaetotaxy.* AF1 slightly nearer to F1 than to AF2; AFa very close to AF1, sometimes behind, sometimes on one side, and sometimes slightly in front of AF1. V setae about equidistant from one another and in a more or less straight line; Va usually but not always in the same line and usually slightly nearer to V2 than to V3. P1 close to AF1; P2 postero-laterad from P1 and at about the level of AF2; Pb directly mesad from P2 and about half way between it and adfrontal suture; Pa more or less directly laterad from P1 and nearer to A3. Aa laterad from A2, often nearly as far behind as A2, and somewhat closer to latter than to A1. O2 about half again as far from O1 as from O3; Oa antero-laterad from O2 and with another puncture close to and laterad from O1. SO group forming a nearly equilateral triangle with SOa in the middle. Ga in front of G1 and sometimes slightly more dorsal. Prothorax (fig. 165) with a distinct puncture slightly above and behind L1; SV group on the same pinnaculum and in a nearly horizontal line. Mesothorax but not metathorax with D group of right and left sides on the same pinnaculum. Meso- and metathorax with pinnacula of SD1 and SD2 fused; L1, L2, and L3 on separate pinnacula; SV group on the same pinnaculum and in a nearly vertical line; MSD setae in an oblique line and on the same pinnaculum. Abdomen (fig. 162) with SD setae of first or first and second segments on the same



Figs. 162-164.—*Acedes ganomella* (Treit.), mature larva. (162) Dorsal view of eighth to tenth abdominal segments. (163) Right proleg of third abdominal segment. (164) Antenna.



Figs. 165-170.—(165) Dorsal and lateral setae of left side of prothorax of mature larva of *Acedes ganomella* (Treit.). (166) Ventral view of right mandible of same. (167) Left proleg of tenth abdominal segment of same. (168) Antenna of mature larva of *Acedes semifulvella* (Haw.). (169) Dorsal and lateral setae of right side of prothorax of same. (170) Spiracle and associated setae of left side of third abdominal segment of same.

pinnaculum but on 2-8 or 3-8 nearly always on slightly separated pinnacula; SD2 antero-dorsad from SD1 and nearly as stout but only about half as long; L1 postero-ventrad from spiracle and in a nearly horizontal line with L2; SV group of 1, 7, and 8 bisetose, of 2-6 trisetose (fig. 163), and of 9 unisetose; on 1-8 SV setae are not on separate pinnacula; ninth segment with D1, D2, SD1, and L1 of both right and left sides on a single pinnaculum; D1 of ninth segment slightly but distinctly nearer to SD1 than to D2; eighth segment with pinnacula of right and left sides of both D1 and D2 fused as shown in fig. 162.

Distribution. Europe, Asia.

Comparative notes. Of the species described in this paper it is close only to *A. semifulvella* (Haw.) from which it may be distinguished as shown under the heading of that species.

Habits. It is recorded by many from bird nests (Meyrick, 1928; Schütze, 1931; Spuler, 1910; Waters, 1928; Wolff & Krausse, 1922). It is said to be an obligate commensal of certain passerine birds like the hedge-sparrow and thrush (Rothschild & Clay, 1952). I have never found the larva except in bird nests. In the laboratory they grow well on soiled fur or feathers. The species has been found in Britain in the nests of chaffinch, greenfinch, carrion crow, hedge-sparrow, bullfinch, moorhen, song-thrush, linnet, sand-martin, house-sparrow, bunting, and warbler (E. B. Basden, personal communication). Notes on its biology are given by Hesse (1923). An unidentified species of *Apanteles* is recorded as a parasite (Schütze & Roman, 1931).

***Acedes semifulvella* (Haworth) (1828) (figs. 168-174).**

Mature larva. Length, 7.0-8.5 mm.; breadth, 1.5-1.8 mm.

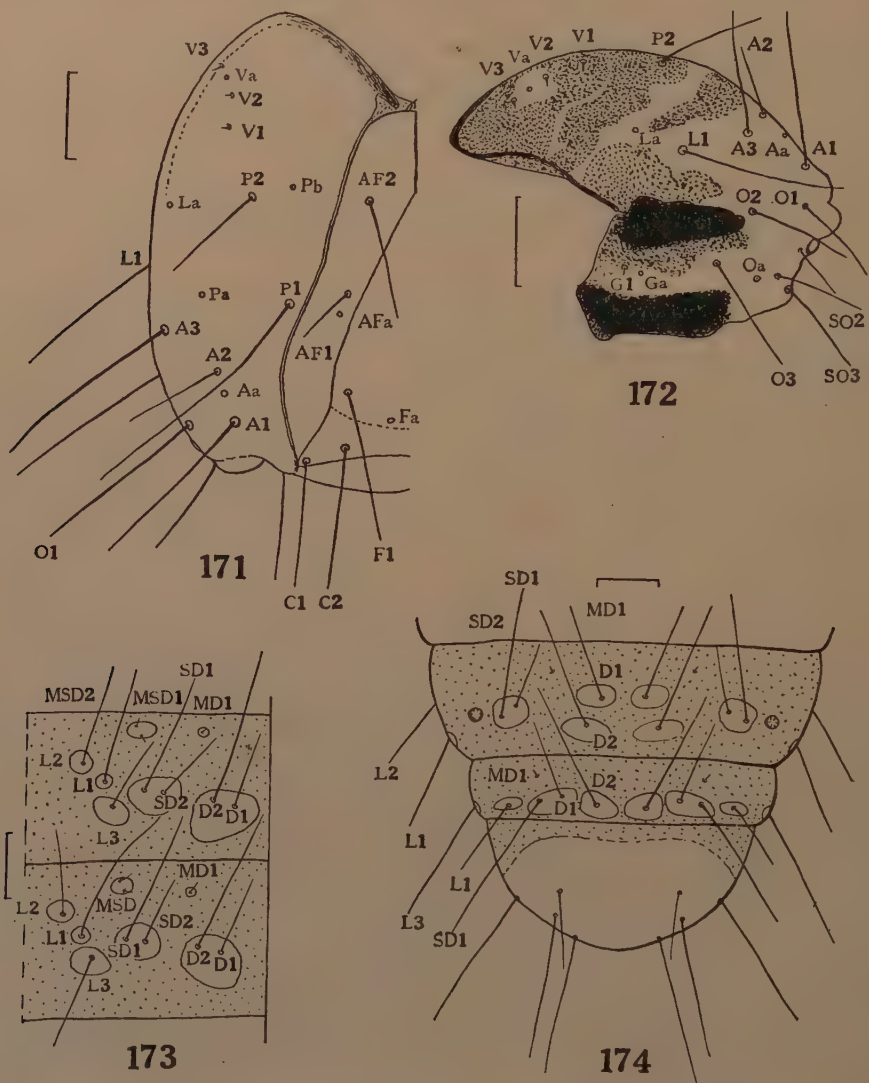
Externally similar to *A. ganomella* (Treit.) but differs as follows: (1) Head distinctly mottled with darker brown, as shown in fig. 172; darker patches correspond to the origins of the mandibular muscles. (2) Antenna with meso-ventral cone of apex of second segment (fig. 168) as long or longer than third segment plus its seta instead of distinctly shorter as shown in fig. 164. (3) Ventral prolegs usually with 27-30 crochets instead of 13-15 crochets. (4) Aa between and in a line with A1 and A2 (fig. 171) instead of distinctly laterad from these setae. (5) Mesothorax (fig. 173) with pinnaculum of D1 + D2 of right side not fused to pinnaculum of D1 + D2 of left side. (6) Abdomen with pinnacula of neither D1 nor D2 of right and left sides of eighth segment fused across dorsum (fig. 174). (7) SD1 and SD2 of first eight abdominal segments always on same pinnaculum (fig. 170). (8) Ninth abdominal segment (fig. 174) with D1 and SD1 on same pinnaculum but D2 and L1 on their own pinnacula, and pinnacula of right and left sides never fused as in *A. ganomella* (fig. 162). And (9) eighth and ninth abdominal segments with pinnacula of V setae of right and left sides separate instead of fused.

Distribution. Europe.

Habits. The larva of this, like *A. ganomella*, lives in a portable case which has an opening at either end. The case of both species is much rougher on the outside than is that of *Tinea pellionella* or *T. columbariella* and is broadly elliptical in cross section. In comparison with these species of *Acedes*, the larval cases of *Tinea* are much flattened.

A. semifulvella has been found in the nests of various kinds of birds, e.g., Meyrick (1928) and Schütze (1931). I have not found it in bird nests in Britain, but I have frequently found it breeding in partly decayed woollen clothes left out-of-doors, and on one occasion (v.1944) two larvae were found feeding on the wool

of a dead sheep at Linton, Cambridgeshire. Spuler (1910) records it from fungi, but it seems unlikely that the larvae normally attack fungi.



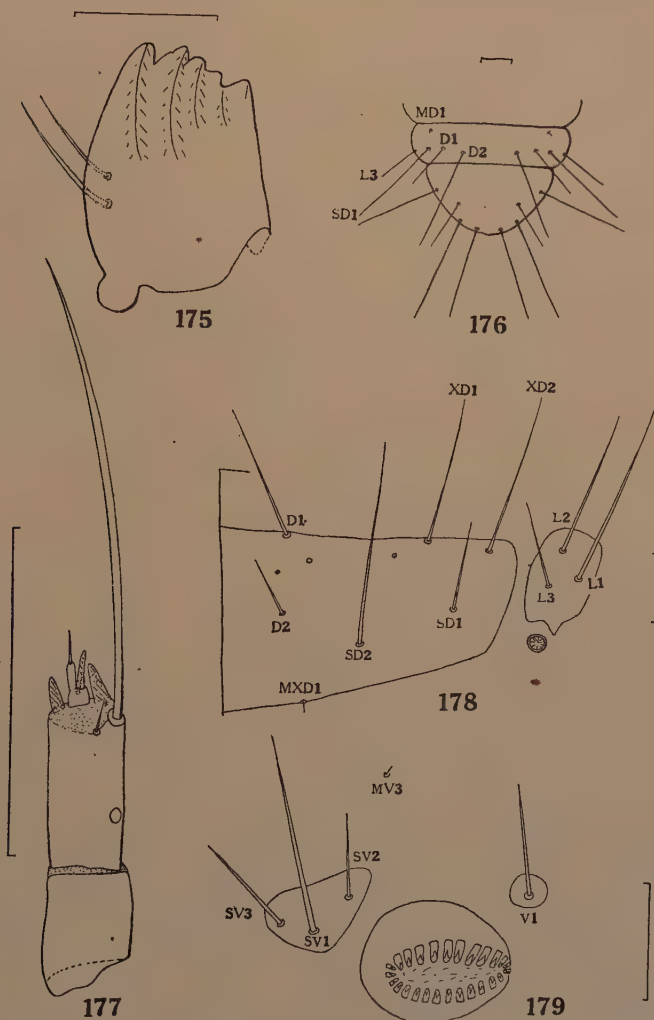
Figs. 171-174.—*Acedes semifulvella* (Haworth), mature larva. (171) Dorsal view of right side of head. (172) Right side of head. (173) D, SD, MD, MSD, and L groups of meso- and metathorax. (174) Dorsal view of eighth to tenth abdominal segments.

***Acedes pallescentella* (Stainton) (1851) (figs. 175-183).**

Mature larva. Length, 7-12 mm.; breadth, 1.5-2.0 mm.

Head moderately dark to dark brown with adfrontal areas and often fronto-clypeal apotome darker; anterior, occipital, and parts of ventral margin as well as hypostomal "suture" black or nearly so; on each side at level of ocellus with a broad, black or nearly black, longitudinal stripe that extends from occipital

margin to seta O2 or slightly beyond; tergal and pleural plates of prothorax moderately dark yellowish or reddish brown; tergal plate of tenth abdominal segment usually distinctly paler brown; sometimes with dorsal pinnacula of meso- and metathorax pale brownish; dorsal parts of legs yellowish to moderately dark



Figs. 175-179.—*Acedes pallescentella* (Staint.), mature larva. (175) Ventral view of right mandible. (176) Dorsal view of ninth and tenth abdominal segments. (177) Antenna. (178) Dorsal and lateral setae of right side of prothorax. (179) Right proleg of fifth abdominal segment.

brown; peritreme of spiracles moderately pale brown; cuticle elsewhere white or nearly white with pinnacula indistinct or, more rarely, distinct (mag. $\times 75$); surface of cuticle with dense, slender, pointed microtrichia, each of which arises from a fine tubercle. Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending three-fourths of distance to vertical triangle; on each side with a single convex ocellar lens near anterior margin between SO2 and O1;

surface of head with moderately dense microscopic punctures which become sparser posteriorly and with numerous fine, irregular, usually transverse rugae. Coxae of middle and hind legs widely separated; front coxae only about three-fifths as widely separated as those of middle legs; pinnacula of V1 setae completely fused to coxae. Ventral prolegs (fig. 179) usually with about 28–31 crochets but some smaller full-grown specimens with 23–26 crochets; anterior crochets broader and longer than posterior ones; ellipse of crochets not evidently open on mesal side even when proleg is fully evaginated. Spiracles circular or nearly so; spiracles of eighth abdominal segment nearly twice as large as those of seventh and about a third larger than those of prothorax. *Chaetotaxy*. Cranial setae as shown in figs. 171–172 for *A. semifulvella*; AFa close to and usually in front of AF1; Aa only slightly in front of A2 and almost as far laterad from it as is distance between A1 and A2; V1 usually about half way between V2 and P2 but sometimes nearer the latter; O2 about as far from O3 as from A3 or L1 and only slightly further from O1; Oa in front of O3 and between it and O2; SO setae forming a nearly equilateral triangle with SOa nearly in the middle of the triangle; Ga before and also often slightly above G1. Prothorax (fig. 178) with SV setae in a nearly horizontal line and on the same pinnaculum. Metathorax like mesothorax (fig. 180), and also with pinnaculum of D1 + D2 of right side fused to that of left. Abdomen (figs. 176, 181–183) with SD1 and SD2 of first segment on same pinnaculum; ninth segment with pinnacula of D2 and D1 + SD1 sometimes separate and sometimes incompletely fused; SV group of 1, 7, and 8 bisetose, of 2–6 trisetose, and of 9 unisetose; on 1–8 SV setae always arising from same pinnaculum.

Distribution. Europe. Recently introduced into North America.

Comparative notes. This is very closely related to *A. fuscipunctella* (Haw.) from which it may be distinguished as shown under the heading of that species.

Habits. It has been found by me in numbers in stables, outhouses, mills, granaries, warehouses, and houses in various parts of England. Other records from Britain are, shoe warehouse (Bradley, 1895), in houses and offices (Clutterbuck, 1925; Farren, 1886; Jordan, 1889; Machin, 1870; Sich, 1912, 1915, 1918; Waters, 1928), and bred from hare (Adkin, 1913a) and rabbit (Adkin, 1914) hair.

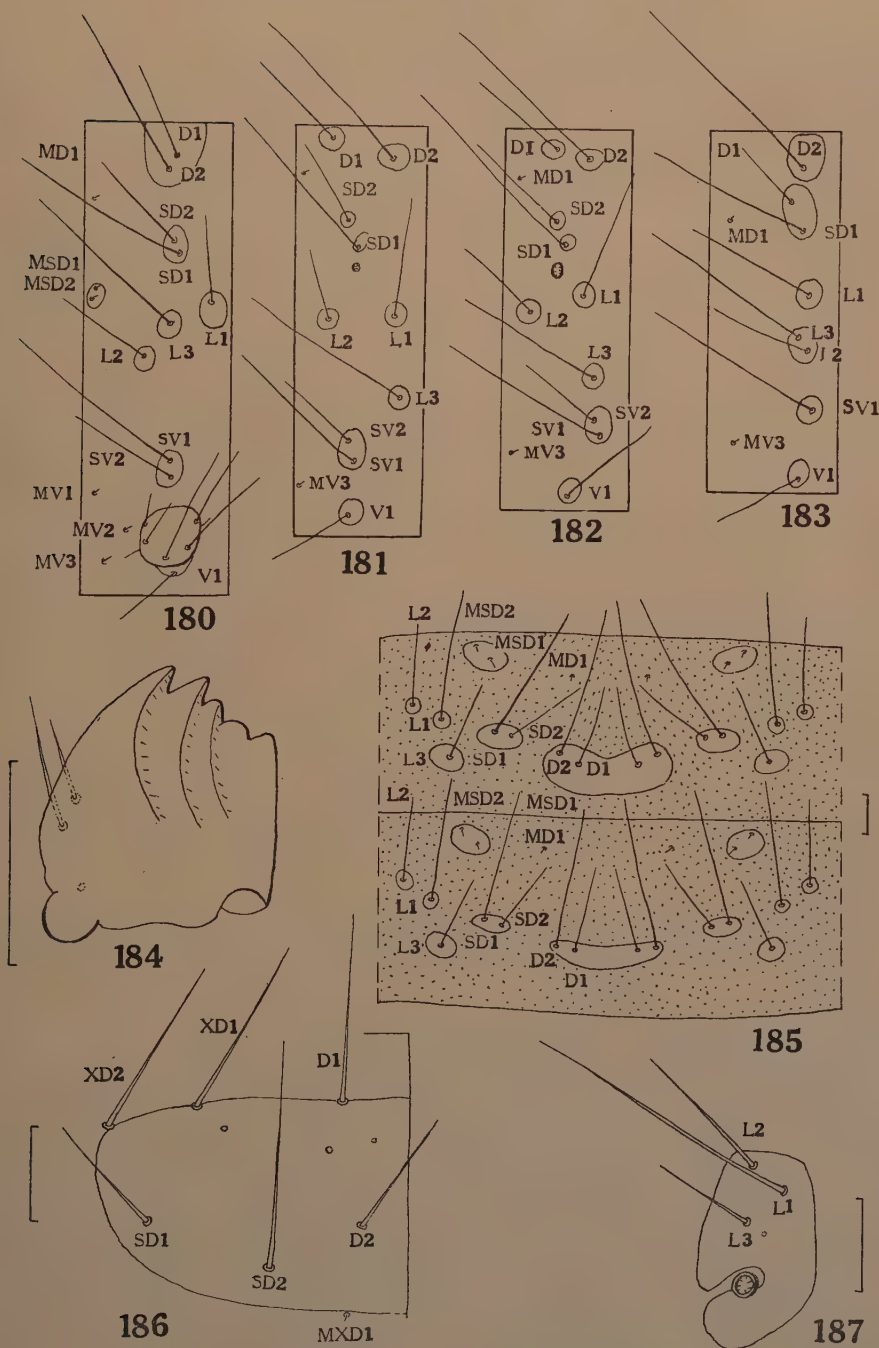
Larvae have been taken by me on a number of occasions in woollen materials and skins left out-of-doors. It has been found on a dead cat (Eales, 1872) and on a dead pheasant (Prevett, 1954), and it has been bred from the nest of *Vespa germanica* F. (Barrett, 1894). A summary of the early literature on *A. pallescentella* is given by Adkin (1914), notes on its biology by Stamm (1940), and notes on its occurrence in Norway by Knaben (1945). *Phygadeuon bitinctus* (Grav.) (Richards, 1949) appears to be the only parasite recorded from it.

***Acedes fuscipunctella* (Haworth) (1828) (figs. 184–187).**

Mature larva. Very similar in size, colour, and external structure to *A. pallescentella* (Staint.), from which it may be distinguished as follows: (1) mandible (fig. 184) more quadrate and less narrowed apically than that of *A. pallescentella* (fig. 175); (2) prothorax (fig. 186) with XD1 twice or more than twice as far from D1 as from XD2 instead of only about $1\frac{1}{2}$ times as far (fig. 178); and (3) SD1 and SD2 of first abdominal segment on separate pinnacula instead of on same pinnaculum.

Distribution. Cosmopolitan.

Habits. It is commonly recorded out-of-doors in bird nests, where it may be supposed to feed on feathers and hair, as do other species of *Acedes*. I have



Figs. 180-187.—(180) Mesothorax of mature larva of *Acedes pallescentella* (Staint.). (181) Seventh abdominal segment of same. (182) Eighth abdominal segment of same. (183) Ninth abdominal segment of same. (184) Ventral view of right mandible of mature larva of *Acedes fuscipunctella* (Haw.). (185) Dorsal and lateral setae of meso- and metathorax of same. (186) Dorsal setae of left side of prothorax of same. (187) Spiracle and L group of prothorax of same.

found that in the laboratory the larva will feed readily on hair, wool flannel, and soiled feathers. In bird nests it is also said to feed on the faeces of young birds (Patton, 1931). In Europe it has been found in the nests of swallow, house-martin, Tengmalm's owl (*Aegolius funereus*), woodpecker (*Dryobates major*), redstart, domestic pigeon, stock-dove, jackdaw, and kestrel (Nordberg, 1936). It has also been found in sparrow nests (Schütze, 1931; Woodroffe, 1953). It may be bred from nests long after they have been abandoned by the birds (Leleup, 1947). It is also common in bird nests in the United States (Milum, 1953), and it has been recorded from those of purple martin, sparrow, house-wren, blue bird, and crested flycatcher (McAtee, 1929) and domestic pigeon (Forbes, 1923) in that country. Rau (1930) found it in the nests of a wasp, *Polistes annularis* (L.), in North America. The larva is said to have been found among seeds of grass in the field (Reh, 1928).

In Britain, it has been found in stables (Ford, 1931, recorded as *Tinea nigripunctella*) and in houses (Barrett, 1878; Farren, 1886; Walsingham, 1907; Waters, 1928; Whittle, 1899; Wilkinson, 1898), and it has been found in an inn in Portugal (Stainton, 1881) and houses in India (Fletcher, 1920). Other records are: damaging book-bindings, mostly of pigskin in Hamburg (Reh, 1928), in bedding in Norway (Schøyen, 1916), and in a woody fungus in a wine vault in Dublin (Barrett, 1872). It has been recorded infesting dried fruit, seeds, and peas in store (Hartmann, 1879). Records of the occurrence of the adults on various commodities in Britain during the years 1946 to 1954 are as follows: in Canadian wheat in a ship at Glasgow; on maize residues, Australian grain, Turkish pollards, Argentine linseed cake, almonds from Tripoli, and Californian prunes in ships at Liverpool; Argentine pollards in a ship in London; in flour mills in London, Oxfordshire, and Co. Durham; in a flour warehouse in Southampton; in a flour store in Hatfield, Herts.; in provender mills in Lancashire and Northumberland; and in a rice mill in London.

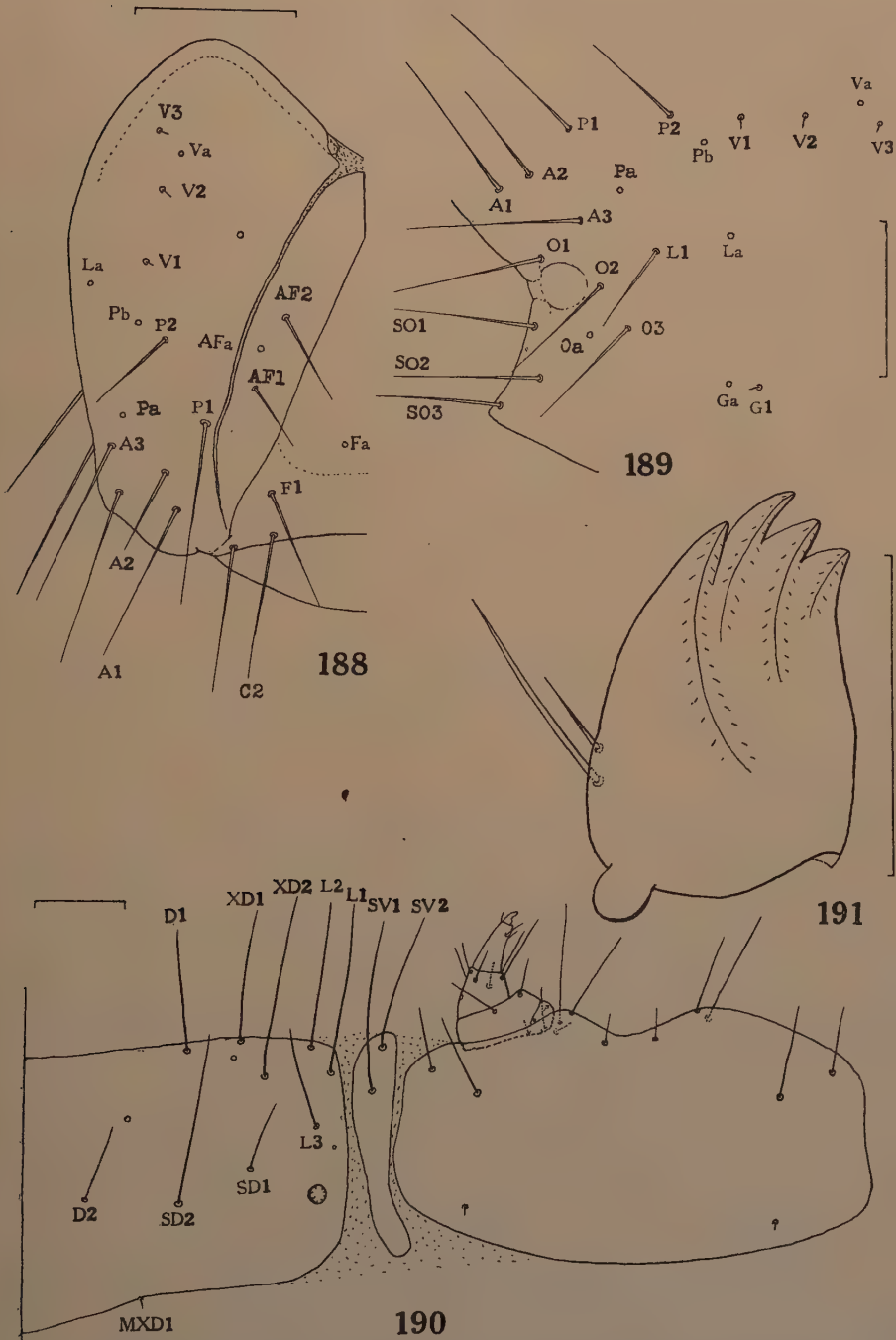
According to Milum (1953), the larvae seem to be unable to feed on whole kernels of wheat, and they did not develop on wheat alone but may feed on mite excrement and other refuse. In wheat they were often surrounded by large numbers of mites (*Tyroglyphus lintneri* (Osb.)) which, however, did not seem to injure them.

The surface sculpture of the egg of this and other Tineids is described by Pappenheim (1938). According to Burks (1943), the larva is parasitised by *Apanteles carpatus* (Say).

***Eccritothrix trimaculella* (Chambers) (1873) (figs. 188-191).**

Mature larva. Length, 7 mm.; breadth, 1.2 mm.

Head moderately dark brown with adfrontal areas darker and occipital and parts of ventral margin as well as hypostomal "suture" black or nearly so; each side with a narrow, longitudinal, black or nearly black stripe at level of ocellus that extends from occipital margin nearly to seta O₂; tergal and pleural plates of pro- and mesothorax nearly as dark as head, and plates of metathorax somewhat paler; legs and sternal plates of thorax nearly as dark brown as tergal plates; tergal plate of tenth abdominal segment paler; peritreme of spiracles moderately dark brown; pinnacula distinct and cuticle elsewhere whitish; surface of cuticle between pinnacula with dense, slender, and pointed microtrichia, each of which arises from a fine tubercle. Head (fig. 188) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending four-fifths of distance to vertical triangle; each side with a single, large, convex ocellar lens near anterior margin in front of seta O₂. Coxae of all legs completely fused so that each pair occupies whole of sternum as shown in fig. 190; legs very short with broad femora which appear at first sight to be coxae; V1 setae near anterior margin of coxal plates. Ventral



Figs. 188-191.—*Eccritothrix trimaculella* (Chambers), mature larva. (188) Dorsal view of right side of head. (189) Part of left side of head. (190) Tergal, pleural, and sternal plates of prothorax. (191) Ventral side of right mandible.

prolegs with 40–44 crochets; anterior crochets distinctly broader and longer than posterior; ellipse of crochets usually narrowly open on mesal side when proleg is fully evaginated. Spiracles circular or very broadly oval and those of abdomen distinctly projecting above surface; spiracles of eighth abdominal segment about a third broader than those of seventh but not distinctly broader than those of prothorax. *Chaetotaxy*. Cranial setae as in figs. 188–189 and prothoracic setae as in fig. 190. Mesothorax with D, SD, and L setae of both right and left sides on same pinnaculum or sclerotised plate; D group in a transverse line, SD group in a slightly oblique line, and L3 nearly twice as far from L1 as is L2; SV setae in a nearly horizontal line and on same pinnaculum; MD1 in its usual position and its pinnaculum small and indistinct; MSD group in an oblique line and on same pinnaculum, which is dark brown. Metathorax like mesothorax but with pinnaculum of L group not fused to dorsal plate. Abdominal segments 1–4 and 8 with D group of right and left sides on same pinnaculum; 5–7 with pinnacula of D1 setae of right and left sides fused as are pinnacula of D2 setae, but pinnaculum of D1 separate from that of D2; SD2 on same pinnaculum as SD1, in front of and above latter from which it is separated by a distance about equal to that between L1 and L2; L1 and L2 in a nearly horizontal line with L1 behind and far below spiracle. Ninth segment with D1, D2, SD1, and L1 of both sides arising from same pinnaculum; D1 slightly nearer to SD1 than to D2 and scarcely anterior to either. SV group of 1, 8, and 9 unisetose, of 2–6 trisetose, and of 7 bisetose; pinnacula of V1 of right and left sides of segments 7–9 fused and 3–6 nearly fused; segments 1–2 with SV and V groups of both sides on same pinnaculum.

Distribution. North America.

Comparative notes. Its very short legs and fused coxal plates will serve to distinguish it from all other known Tineid larvae.

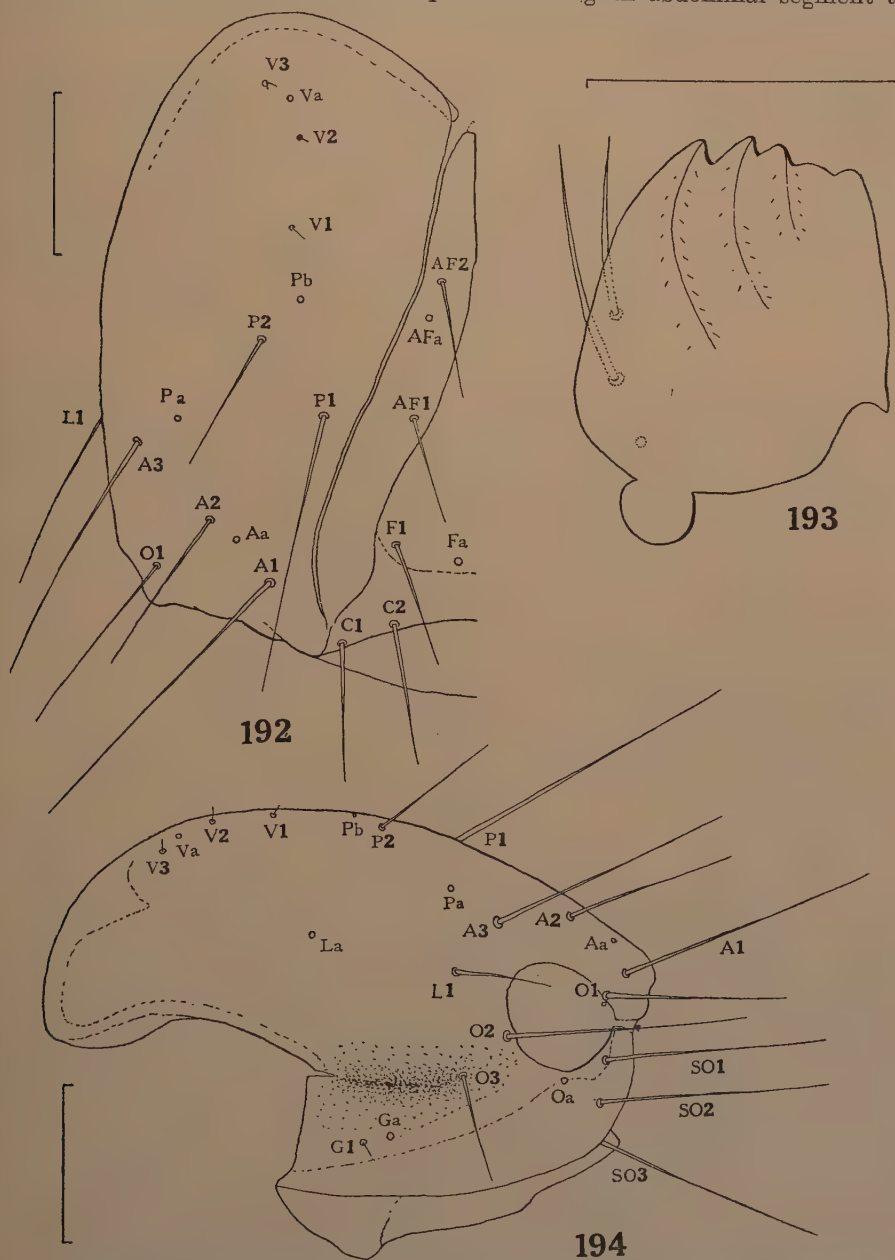
Habits. The larva lives in a flattened, portable case. I believe it is sometimes found in ant nests.

Praeacedes thecophora (Walsingham) (1908) (figs. 192–199).

Mature larva. Length, 8–9 mm.; breadth, 1.5–1.7 mm.

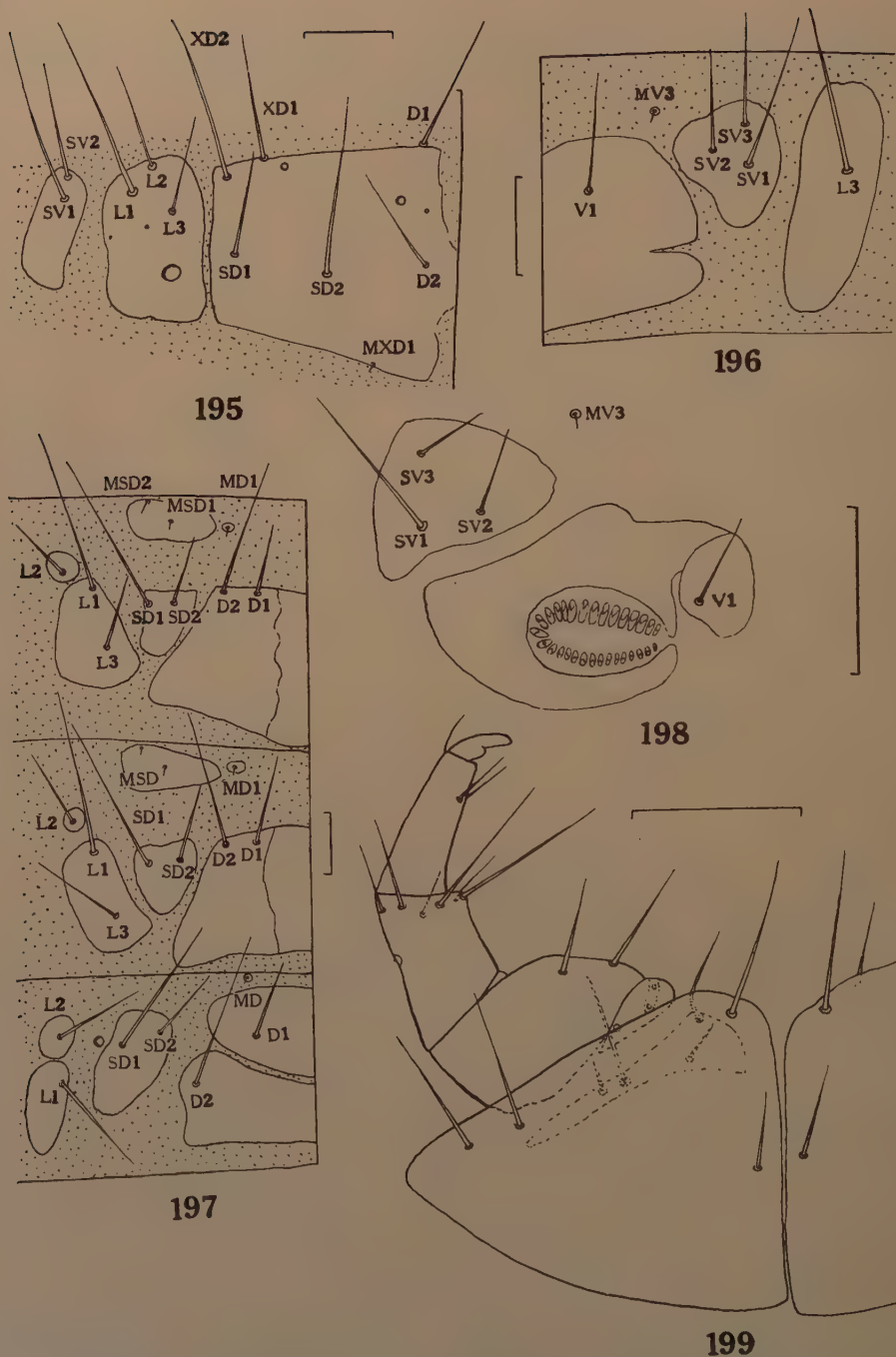
Head moderately dark brown with indistinct darker patches that correspond to origins of mandibular muscles; occipital margin black or nearly so and parts of ventral margin and hypostomal “suture” sometimes nearly black; each side with a very dark brown or black, longitudinal stripe at level of ocellus extending from occipital margin to or slightly beyond seta O3 (fig. 194); tergal and pleural plates of thorax and first or first few abdominal segments moderately dark brown; ventral surface of thorax as darkly or nearly as darkly pigmented as dorsal part of thorax and other pinnacula or sclerotised plates pale brownish or nearly white with tergites of ninth and tenth segments distinctly darker; peritreme of spiracles brown; cuticle between pinnacula white or nearly so and with dense, slender, erect microtrichia, each of which arises from a fine tubercle. Head with part of fronto-clypeal apotome enclosed by adfrontal sutures extending three-fourths of distance to vertical triangle; each side with a single, large, convex ocellar lens near anterior margin immediately before seta O2. Coxae of legs only narrowly separated, those of middle and hind legs very little more separated than front coxae (fig. 199); pinnacula of V1 setae of prothorax completely incorporated in coxal plates; pinnacula of V1 setae of middle and hind legs fused to coxal plates but nevertheless recognisable as such in stained specimens. Ventral prolegs (fig. 198) usually with 27–30 crochets; anterior crochets about twice as long and broad as posterior; ellipse of crochets narrowly open on mesal side, this opening usually evident even when prolegs are not fully

evaginated. Spiracles circular or very broadly oval and with those of abdomen distinctly projecting above surface; spiracles of eighth abdominal segment twice



Figs. 192-194.—*Praeacedes thecophora* (Walsingham), mature larva. (192) Dorsal view of right side of head. (193) Ventral side of right mandible. (194) Right side of head.

as broad as those of seventh and about a fourth broader than those of prothorax. *Chaetotaxy*. Cranial setae as shown in figs. 192 & 194. Thorax (figs. 195 & 197)



Figs. 195-199.—*Praeaccedes thecophora* (Walsingham), mature larva. (195) Dorsal, lateral, and subventral setae of left side of prothorax. (196) Pinnacula of V, SV, and L3 setae of right side of second abdominal segment. (197) Dorsal and lateral setae of left side of meso- and metathorax and first abdominal segment. (198) Right proleg of sixth abdominal segment. (199) Ventral side of prothoracic leg.

with SV setae on same pinnaculum and in a nearly horizontal line on all three segments. Abdomen (fig. 197) with pinnacula of D1 of right and left sides of first eight segments fused as are pinnacula of D2 of right and left sides, but both pinnacula on some segments (in stained specimens) with a pale, narrow, median longitudinal line; pinnacula of SD1 and SD2 completely fused on 1-6 and nearly completely fused on 7-8, with SD2 above and before SD1 and about two-thirds as far from the latter as is L2 from L1; pinnacula of L1 and L2 contiguous or nearly so on anterior segments but distinctly separated on eighth. Ninth segment with D1, D2, SD1, and L1 of right and left sides on a single pinnaculum; D1 only slightly nearer to SD1 than to D2 and slightly anterior to both. SV group of 1, 7, and 8 bisetose, of 2-6 trisetose, and of 9 unisetose; SV pinnacula of first two segments nearly completely fused to V1 pinnacula; all SV groups of a side on same pinnaculum. V1 pinnacula of first two abdominal segments completely fused as are those of ninth; V1 pinnacula of eighth nearly contiguous but those of 3-7 distinctly separated.

Distribution. Tenerife, Nigeria.

Comparative notes. In many respects this is related to *Phereoeca allutella* (Rebel), *P. uterella* (Wals.), and *P. walsinghami* (Busck), but it differs particularly in having the front coxae narrowly separated and the D, SD, and L groups of the meso- and metathorax on separate pinnacula. The head is somewhat dorso-ventrally flattened, as in the species of *Phereoeca*, and the position of O3 is very unusual (fig. 194). I have examined shed cuticles of larvae from which the type series was bred as well as larvae collected in Nigeria.

Habits. The larva lives in a portable case which is described by Walsingham (1908) as, "Case dust-coloured, elongate, ovate, flattened; very distinct from that of *pellionella* L. or *allutella* Rbl. It is not bottle-shaped, nor visibly indented on any part of the margin, and is smooth and formed of grains of dust and woolly refuse, but is smooth and dense in texture, and is open at both ends, cleanly cut, evenly rounded, and without ragged edges."

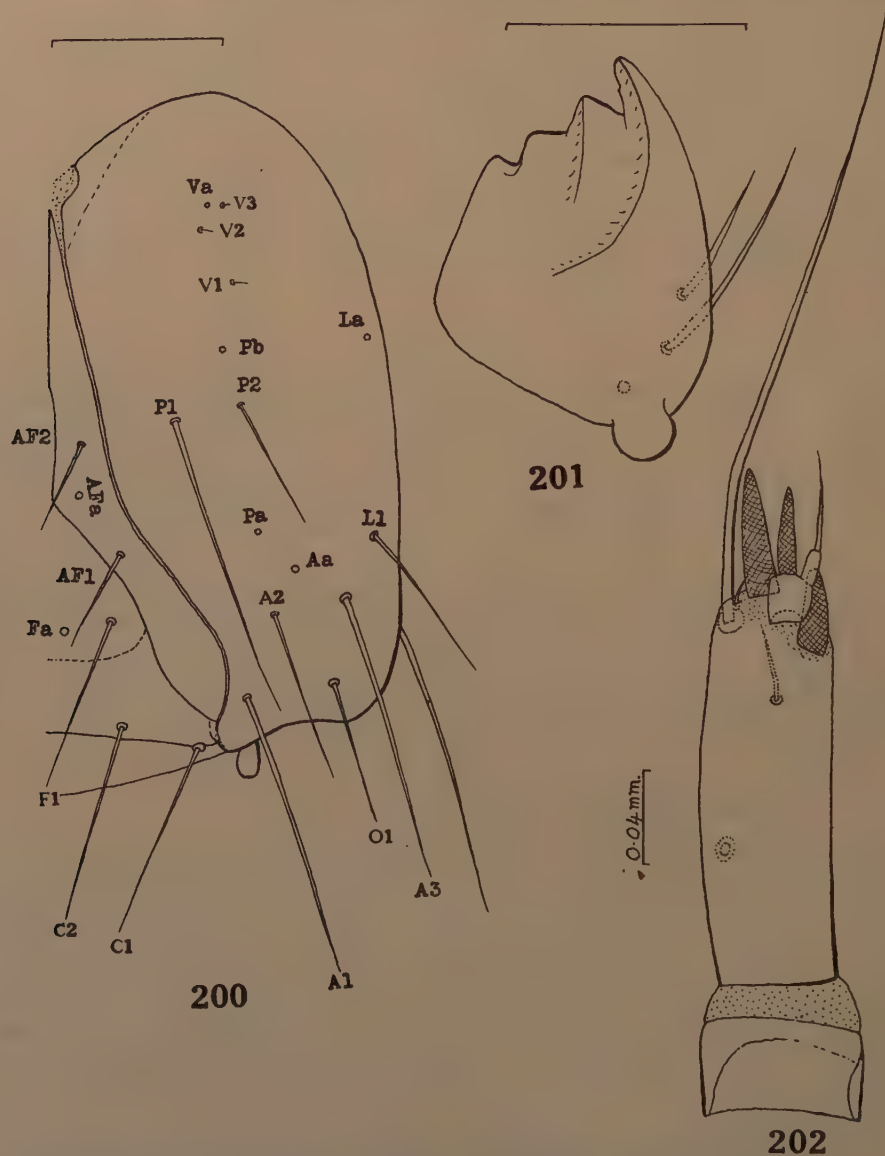
It has been found in numbers crawling on walls in houses both in Tenerife and Nigeria.

Genus (?) and species (?) (figs. 200-209).

Mature larva. Length, 7.5 mm.; breadth, 1.5 mm.

Head moderately dark brown with occipital and ventral margins and hypostomal "suture" darker; each side with a distinct, dark brown, longitudinal stripe extending from occipital margin to about O2; sclerotised plates or pinnacula of thorax and most of legs paler to as dark brown as head; peritreme of spiracles moderately pale brown; pinnacula of abdomen pale, moderately distinct; cuticle elsewhere white or nearly so; surface of cuticle with dense, microscopic tubercles which are sometimes pointed but are rarely with points sufficiently slender to be called microtrichia. Head (fig. 200) with part of fronto-clypeal apotome enclosed by adfrontal sutures extending only two-thirds of distance to vertical triangle and with somewhat more than posterior third (6:16) abruptly and strongly narrowed; if an ocellar lens is present on each side near anterior margin, it is not evident in single specimen available. Coxae of front legs (fig. 207) completely fused, coxae of middle legs nearly completely fused, and coxae of hind legs (fig. 209) very narrowly separated and with pinnacula of V1 setae fused to coxae. Ventral prolegs with 25-27 crochets; anterior crochets about a third again as long and broad as posterior; ellipse of crochets narrowly but distinctly open on mesal side even when proleg is not fully evaginated. Spiracles of eighth abdominal segment (fig. 205) broadly oval but other spiracles circular or nearly so; spiracles of eighth segment more than twice as broad as those of seventh

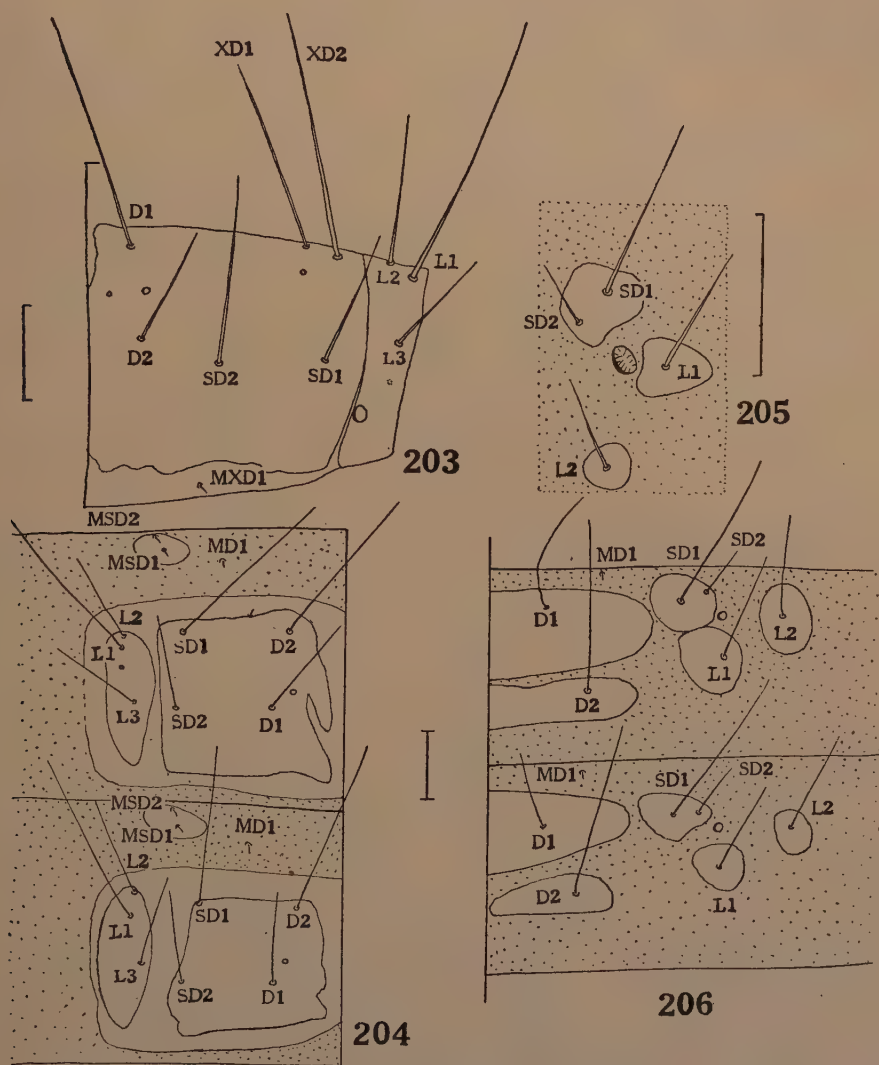
(2·3:1) and about a third broader than those of prothorax. *Chaetotaxy*. Cranial setae as shown in fig. 200; O2 in front of and only slightly more dorsal than O3; SO2 nearer to SO1 than to SO3; two SO punctures near together and between



Figs. 200-202.—Mature larva of an undetermined genus and species from Algeria. (200) Dorsal view of left side of head. (201) Ventral side of left mandible. (202) Antenna.

SO3 and SO2, one as far back as these setae and the other slightly further back; Ga antero-ventrad from G1. Prothorax (fig. 203) with both SV setae on same pinnaculum and in a nearly horizontal line. Meso- and metathorax (fig. 204) with both SV setae on same pinnaculum (fig. 209) and in a nearly horizontal line;

with a distinct puncture antero-dorsad from D1 which is nearer to latter than to D2; pinnaculum of L groups with a puncture behind L1 on mesothorax but on metathorax with similar puncture indistinct or possibly absent. Abdomen

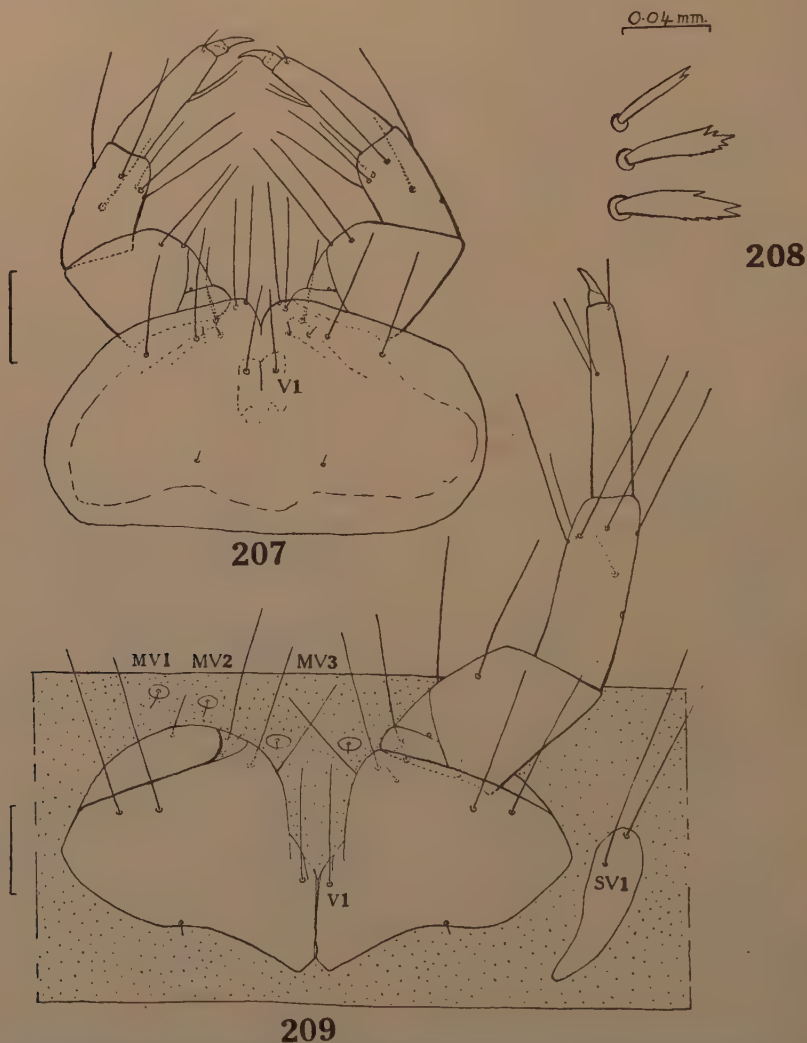


Figs. 203-206.—Mature larva of an undetermined genus and species from Algeria. (203) Dorsal and lateral setae of right side of prothorax. (204) Dorsal and lateral setae of left side of meso- and metathorax. (205) Spiracle and associated setae of left side of eighth abdominal segment. (206) Dorsal and lateral setae of right side of second and third abdominal segments.

(figs. 205-206) with pinnaculum of D1 separate from that of D2 on first eight segments; pinnacula of D1 of right and left sides fused on 1-8; pinnacula of D2 of right and left sides fused on 1-2 and 8, narrowly separated on 3 and 7, and widely separated on 4-6; pinnaculum of SD1 + SD2 fused to that of D1 on 1, nearly fused on 2 (fig. 206), and well separated on 3-8 (fig. 205); L1 and L2 of 1-8

in a strongly oblique line with L1 more or less directly behind spiracle; SV group of 1, 7, and 8 bisetose, of 2-6 trisetose, and of 9 unisetose; each SV group on a single pinnaculum; ninth segment with D1, D2, and SD1 in a nearly straight line and D1 very little nearer to D2 than to SD1.

Distribution. Algeria.



Figs. 207-209.—Mature larva of an undetermined genus and species from Algeria. (207) Ventral side of prothoracic legs. (208) Maxillary spines. (209) Ventral side of metathoracic leg.

Comparative notes. This superficially resembles the larvae of *Phereocca* but it may at once be distinguished from that genus and all other TINEIDAE known to me by having the two D setae and the two SD setae of both the meso- and metathorax in a nearly horizontal line. All other species of the family which I have seen have both of these setal groups in a nearly transverse line, but if one group is not transverse, it is never more than about 45° from the transverse.

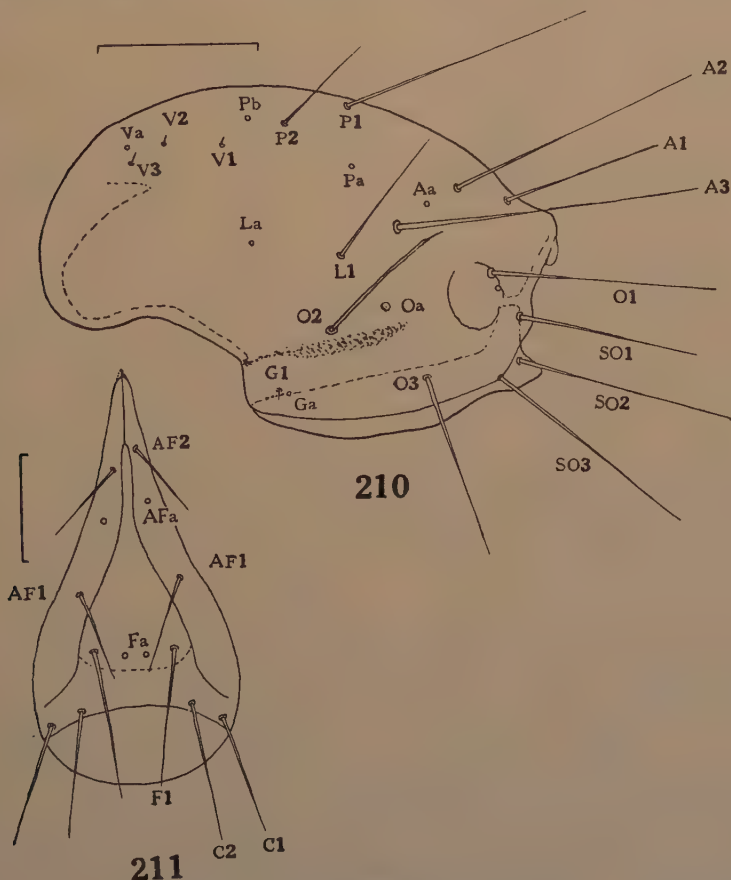
The punctures on the tergal and pleural plates of the meso- and metathorax are further very unusual features not only for the family TINEIDAE but for any of the more primitive diplotreme families. I know of no other Tineid which has the three spines on the maxillary lobe denticulate (fig. 208).

The adults of this species have been identified by others as *Tinea uterella* Wals. or *T. allutella* Rebel. A new genus is required for this species, but one is not erected here because I am not certain to which, if any, of the already described species of *Tinea* (s. lat.) it belongs.

Habits. It has been taken crawling on the walls in houses in Algeria.

***Phereoeca uterella* (Walsingham) (1897) (figs. 210–216).**

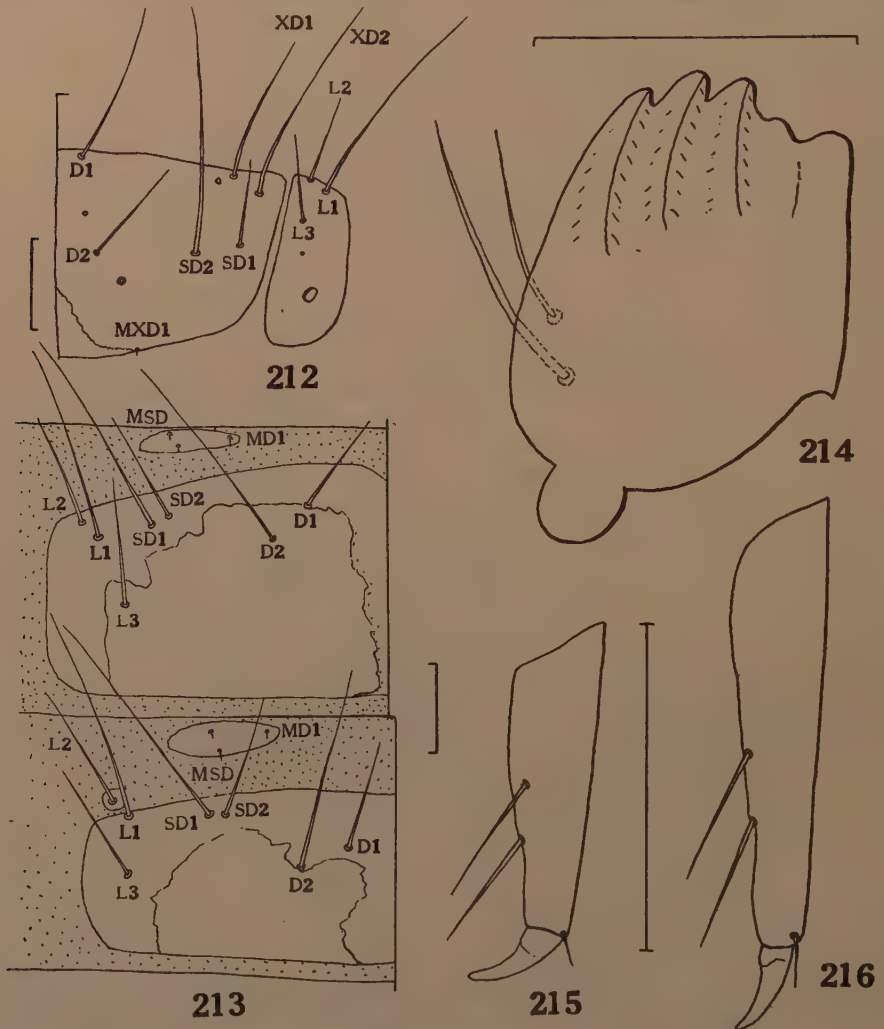
Mature larva. Length, 7 mm.; breadth, 1.5 mm. (estimate from shed cuticles of final-instar larvae).



Figs. 210–211.—*Phereoeca uterella* (Walsingham), mature larva. (210) Right side of head. (211) Fronto-clypeal apotome.

Head dark brown with poorly defined but large paler areas especially on posterior half; anterior margin and hypostomal "suture" darker; on each side above G group with a dark brown or nearly black, narrow, longitudinal stripe extending from posterior margin as far as O2 or, in some specimens, as far as ocellus (fig. 210); prothorax with tergal and pleural plates about as dark as head;

tergal and pleural plates of meso- and metathorax nearly as dark as those of prothorax; legs brownish with coxal plates moderately pale to moderately dark brown; peritreme of spiracles pale brown; cuticle between pinnacula and sclerotised plates white or nearly so, with pinnacula of abdomen indistinct or



Figs. 212-216.—*Pheroeca uterella* (Walsingham), mature larva. (212) Dorsal and lateral setae of right side of prothorax. (213) Dorsal and lateral setae of left side of meso- and metathorax. (214) Ventral side of right mandible. (215) Tarsus of front leg, microtrichia not shown. (216) Tarsus of hind leg, microtrichia not shown.

not visible; surface (mag. $\times 75$) of cuticle densely, microscopically tuberculate, with tubercles often feebly convex or nearly flat-topped but parts of "inter-segmental" membrane between thoracic tergal and pleural plates with microtrichia arising from tubercles. Head (fig. 210) slightly but distinctly flattened; part of fronto-clypeal apotome (fig. 211) enclosed by adfrontal sutures extending about three-fourths of distance to vertical triangle; each side with a large, convex,

ocellar lens near anterior margin below seta O1; surface with a dense and distinct reticulate (or evenly punctate) microsculpture, this becoming sparser posteriorly; surface also with fine, irregular, indistinct rugae. Coxae of right and left sides of front and middle legs completely fused and those of hind legs as completely fused posteriorly but separated anteriorly; V1 setae on anterior third of coxal plates. Ventral prolegs usually with 23–25 crochets; anterior crochets at least a third broader and longer than posterior ones; ellipse of crochets narrowly open on mesal side but this not evident when proleg is partly retracted. Spiracles circular or nearly so; spiracles of eighth abdominal segment more than twice as broad as those of seventh (6:2.1) and half again as broad as those of prothorax (6:4); peritreme of prothoracic spiracles distinctly projecting above adjoining surface. *Chaetotaxy*. Cranial setae as shown in figs. 210–211. Prothorax (fig. 212) with SV setae in a nearly horizontal line and on same pinnaculum. Meso- and metathorax (fig. 213) with SV setae in a nearly vertical line and on same pinnaculum. First eight abdominal segments with pinnacula of D1 setae of right and left sides fused as are pinnacula of right and left sides of D2 setae; SD2 slightly above and far in front of SD1; pinnacula of SD setae apparently always separate; L1 and L2 in a slightly oblique line with L1 below and behind spiracle. SV group of 1, 7, and 8 unisetose, of 2 bisetose, and of 3–6 trisetose; SV group of 9 appears to be unisetose, but available material is not in good enough condition to be certain of this. Ninth segment with D1 slightly nearer to SD1 than to D2 and both D setae slightly in front of SD1.

Distribution. Brazil.

Comparative notes. The only other larvae of *Phereoeca* I have seen are those of *P. walsinghami* (Busck) and *P. allutella* (Rebel). From these *P. uterella* may be distinguished by having D2 of the metathorax about twice as far from SD2 as from D1 instead of having D2 only about $1\frac{1}{2}$ times as far from SD2 as from D1. It may, however, be supposed that when a more extensive series of *P. uterella* is examined some will not be distinguishable in this way from *P. allutella* and *P. walsinghami*.

Habits. It probably feeds on keratins like other members of the genus. Previous records of the habits of this species refer in fact to either *P. allutella* (Rebel) or to *P. walsinghami* (Busck), as has been noted by Busck (1934).

***Phereoeca allutella* (Rebel) (1892).**

Mature larva. Similar in size and external structure to *P. uterella* (Wals.) from which it may be distinguished by having D2 of the metathorax only about $1\frac{1}{2}$ times as far from SD2 as from D1. As already noted under the heading of *P. uterella*, this structural difference will very probably not prove to be satisfactory for distinguishing all individuals of the two species.

Distribution. Canary Islands. Probably widely distributed in the Old World.

Habits. It is apparently common in houses in the Canary Islands (Walsingham, 1908). *Tinea pachyspila* Meyrick (1905) is said to be a synonym of *P. allutella* (Rebel). I have been able to examine only a single and incomplete shed cuticle of the last-instar larva. This piece of cuticle is similar in all particulars to *P. allutella*. It is therefore evident that *Tinea pachyspila* belongs to the genus *Phereoeca*, but, owing to the extreme similarity of different species of the genus, this resemblance cannot by itself be taken seriously as evidence that *P. pachyspila* is a synonym of *P. allutella*. The species known as *pachyspila* is a common domestic species throughout India (Fletcher, 1920). It has been found attacking flannel and furs in Ceylon.

Phereoeca walsinghami (Busck) (1934).

Mature larva. Apparently externally identical with that of *P. allutella* and differs in the same particulars as the latter from *P. uterella*.

Distribution. West Indies, Florida.

Habits. It is a common domestic species in the West Indies. The larva feeds on insect remains caught in spiders' webs (Busck, 1934). Busck claims that it does not feed on fabrics, but Watson (1939) records it as a pest of woollen materials of all kinds in Florida.

Habits of Species of which no Larvae are available.

With the exception of *Tineola furciferella* Zagulyaev, *Trichophaga percna* Corbet & Tams, *Monopis crocicapitella* (Clem.) and *M. ethelella* (Newman), most of the species listed below appear to be of little significance as pests.

Crypsithyris longicornis (Stainton) (1859).

The larva lives in a portable case. It has been found on silk and on refuse in houses. It occurs in India, Ceylon and Java.

Tineola furciferella Zagulyaev (1954).

This species is widely distributed in the central parts of the Soviet Union, where it is more important as a pest of furs, pelts, and wool than *Tineola bisselliella* (Humm.). An account of its life-history and descriptions of its immature stages are given by Zagulyaev (1954).

Trichophaga percna Corbet & Tams (1943).

In the Oriental Region, where this species replaces *T. tapetzella* (L.) as a pest of furs, skins, woollen materials and feathers (Fletcher, 1916; Patton, 1931), it has been known as *T. abruptella* (Woll.). In the British Museum there are no specimens of *T. abruptella* from the Oriental Region (Corbet & Tams, 1943b). The latter species is widely distributed in Africa and also occurs in Spain, Iraq, Palestine, Arabia and the Canary Islands.

Monopis crocicapitella (Clemens) (1859).

This species is occasionally found indoors. In England it has been bred from the debris of carpets (Bankes, 1912) and has been found breeding in the felt lagging of a water pipe in a house (Woodroffe & Southgate, 1952). During the years 1948 to 1954 larvae were found in Australian oats spillage in a ship in Liverpool, and adults were found in flour mills in Devon, London and Surrey, in provender mills in Somerset, and on Canadian flour on a London wharf. In North America, it has been bred from refuse and from seeds of absinth, and it has also been found in a bat cave (Forbes, 1923). The larvae have been found on several occasions in pigeon nests in England (Woodroffe, 1953).

Monopis dicycla Meyrick (1905).

The larva is said to destroy wool in Ceylon.

Monopis ethelella (Newman) (1856).

This species is known to attack wool in store in Australia (Davidson, 1932) and New Zealand (Myers, 1922). It has also been recorded attacking opossum skins in New Zealand (Clark, 1929). Notes on its life-history have been given by Myers.

Monopis fenestratella (Heyden) (1863).

Adults were once found in numbers in a house in France (Smart, 1917).

Monopis monachella (Hübner) (1796).

This is a common European species said to be widely distributed in Africa and the Oriental Region, and has also been reported from the Hawaiian Islands. It is common in houses in the warmer parts of the world, where it has been found feeding on skins (Patton, 1931). In Europe it has been found in bird nests and in the hair of a dead deer (Schütze, 1931).

Monopis pseudagyrtia Meyrick (1919).

This is an Indian species said to be common in houses in Shillong (Patton, 1931).

Monopis trimaculella (Snellen) (1885).

This Indo-Australian species has been found on rabbit skins in Australia.

Scleroplasta liberiella (Zeller) (1879).

Larvae have been found attacking the pelt of a wild cat in Sierra Leone.

Tenaga inquisitrix (Meyrick) (1916).

It has been recorded from houses in India as *Macraeola inquisitrix* Meyr. (Patton, 1931).

Tinea flavescens Haworth (1828).

This is the *Tinea merdella* of British writers but not of Zeller (1847), according to Walsingham (1907) and Pierce & Metcalfe (1934b). In July 1951, a few adults were found on fabric in a flour store at Sunbury, Middlesex. It has been found in houses in England (Bloomfield, 1902; Pyett, 1902), Wales (Barrett, 1878), and Ireland (Kane, 1900). Corbet & Tams (1943a) claim that the larva feeds on furs and woollens.

Tinea metonella Pierce & Metcalfe (1934).

This is a European species. According to Corbet & Tams (1943a), it probably feeds on woollens.

(Tinea ?) nigripunctella Haworth (1828).

The few records of the habits of this species suggest that it may only accidentally enter buildings: in the lavatory of a house in Folkestone (McLachlan in Walsingham, 1894), on the door posts of a hospital in Ipswich (Bloomfield, 1902), in houses in Dublin (Kane, 1900), and on the wall of an outhouse in Chiswick (Sich, 1909b). According to Spuler (1910), the larvae are found in cases on lichens. This species is almost certainly not one of the TINEINAE but may belong to the subfamily NEMAPOGONINAE.

(Tinea ?) nucivora (Meyrick) (1939).

This species has been bred in Malaya from larvae feeding on copra dust (Meyrick, 1939).

Summary.

Keys are provided for the larvae of 32 species of TINEIDAE, and detailed descriptions are given of 31 species. These include most of the species known to be of any economic importance. What is known of the biology of each is briefly summarised, but no attempt has been made to collate the available information on control measures.

No larvae have been available of four species of some economic importance nor of twelve others of doubtful status as pests. The literature on each of these species is noted.

The larvae of a few species of no known economic importance are described and are included in the keys. Most of these are very closely related to species known to be pests.

The keys and descriptions include 21 species which are indigenous to Britain or are established here, so that keys and descriptions are now provided for half of the British species of TINEIDAE.

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References.

(Papers indicated by an asterisk have not been seen by me.)

- *ANON. (1931). Report of the activities of the Central Hygienic Institute and organisations dependent on it in 1930. Department of Parasitology. [In Serbian.]—Socij.-med. Pregl., **2**, pp. 119-123.
- ANON. (1941). Insect pests.—Agric. Gaz. N.S.W., **52**, pp. 531-535, 539.
- ANON. [1943]. Entomological investigations.—16th Rep. Coun. sci. industr. Res. Aust., 1941-42, pp. 14-21.
- ANON. (1949). Statens Skadedyrlaboratorium Årsberetning 1948-1949.—26 pp. Springforbi, Denmark.
- ADKIN, R. (1913a). *Tinea pallescentella* bred from hare's hair.—Proc. ent. Soc. Lond., **1913**, pp. xviii-xix.
- ADKIN, R. (1913b). Is *Tinea pallescentella* granivorous?—Entomologist, **46**, pp. 169-170.
- ADKIN, R. (1914). *Tinea pallescentella*, Stainton (= *nigrifoldella* Gregson). Some notes on its life-history and its history.—Proc. S. Lond. ent. nat. Hist. Soc., **1913-14**, pp. 1-6.

- ADKIN, R. (1923). The Lepidopterous enemies of man, with special reference to species that occur in Britain.—Proc. S. Lond. ent. nat. Hist. Soc., **1922-23**, pp. 26-47.
- ALFIERI, A. (1914). a). Un Hyménoptère parasite des oothèques d'un Blattide. b). Un Hyménoptère parasite des chenilles de *Trichophaga swinhoei* Butl.—Bull. Soc. ent. Egypte, **1913**, pp. 14-15.
- ASTBURY, W. T. (1953). A discussion on the structure of proteins. Introduction.—Proc. roy. Soc., (B) **141**, pp. 1-9.
- AUSTEN, E. E. & HUGHES, A. W. McKenny. (1932). Clothes moths and house moths. Their life-history, habits and control.—Econ. Ser. Brit. Mus. (nat. Hist.), no. 14, 56 pp., 20 figs.
- AVERIN, V. G. (1915). Review of the pests noticed in the Government of Kharkov during 1913. [In Russian.]—Otech. ent. Byu. Kharkov, **1913**, pp. 10-65.
- BACK, E. A. (1935). Clothes moths and their control.—Fmrs' Bull. U. S. Dep. Agric., no. 1353 (revd.), 29 pp.
- BACK, E. A. (1939). House insulation and insect infestations.—Proc. ent. Soc. Wash., **41**, pp. 129-136.
- BACK, E. A. (1945). [Notes on *Prostephanus punctatus* and *Tetrastichus carpatus*.]—Proc. ent. Soc. Wash., **47**, pp. 182-183.
- BACK, E. A. (1946). Protection of mohair fleeces in storage from moths by dipping goats before shearing.—J. econ. Ent., **39**, pp. 721-723.
- BACK, E. A. & COTTON, R. T. (1926). Insect control in upholstered furniture.—Furnit. Warehouseman, **6**, no. 5, repr. 7 pp.
- BACK, E. A. & COTTON, R. T. (1930). Insect pests of upholstered furniture.—J. econ. Ent., **23**, pp. 833-837.
- BACK, E. A. & COTTON, R. T. (1931). The control of moths in upholstered furniture.—Fmrs' Bull. U.S. Dep. Agric., no. 1655, 32 pp.
- BAER, W. (1920-21). Die Tachinen als Schmarotzer der schädlichen Insekten. Ihre Lebensweise, wirtschaftliche Bedeutung und systematische Kennzeichnung.—Z. angew. Ent., **6**, pp. 185-246; **7**, pp. 97-163.
- BAER, W. (1924). Biologische Beobachtungen an Kleidermotten.—Naturw. Korresp., **2**, pp. 122-123.
- BALLARD, R. C. & DAVIDSON, R. H. (1954). Control of mites in clothes moth cultures.—J. econ. Ent., **47**, p. 93.
- BANKES, E. R. (1897). *Tinea cochylidella* Stn., an aberration of *T. ruricolella*, Stn.—Ent. mon. Mag., **33**, pp. 79-80.
- BANKES, E. R. (1910). *Monopis weaverella* Scott (n. syn. = *semispilotella* Strand), specifically distinct from *M. rusticella* Hb.—Ent. mon. Mag., **46**, pp. 221-228.
- BANKES, E. R. (1912). Stray notes on *Monopis crocicapitella* Clms. and *M. ferruginella* Hb.—Ent. mon. Mag., **48**, pp. 39-44.
- BARRETT, C. G. (1872). Notes on species of *Tineina* feeding upon fungi.—Ent. mon. Mag., **8**, pp. 250-251.
- BARRETT, C. G. (1878). Notes on Pembrokeshire *Tineina*.—Ent. mon. Mag., **14**, pp. 268-272.
- BARRETT, C. G. (1887a). Lepidoptera on Cannock Chase.—Ent. mon. Mag., **23**, pp. 195-198.

- BARRETT, C. G. (1887b). Occurrence of *Tinea misella* in corn warehouses.—Ent. mon. Mag., **23**, p. 234.
- BARRETT, C. G. (1888). *Tinea granella* at King's Lynn.—Ent. mon. Mag., **24**, pp. 212-213.
- BARRETT, C. G. (1894). *Tinea pallescentella* in a wasp's nest.—Ent. mon. Mag., **30**, p. 113.
- BENDER, E. (1941). Untersuchungen zur Biologie und Morphologie der in Weinkellern lebenden Kleinschmetterlinge.—Z. angew. Ent., **27**, pp. 541-584.
- BENEDICT, R. C. (1917). An outline of the life-history of the clothes moth, *Tineola biselliella*.—Science, Lancaster, Pa., **46**, pp. 464-466.
- BENEDICT, R. C. (1918). The Yellow Clothes Moth.—Science, Lancaster, Pa., **47**, p. 392.
- BILLINGS, S. C. (1936). Notes on clothes moth breeding.—J. econ. Ent., **29**, pp. 1014-1016.
- BLOOMFIELD, E. N. (1902). Suffolk Lepidoptera in 1901.—Ent. mon. Mag., **38**, pp. 6-7.
- BOUCLIER-MAURIN, H. (1923). Les destructeurs des grains emmagasinés.—Rev. agric. Afr. N., **21**, pp. 412-414.
- BOWER, B. A. (1898). The Tineina of north-west Kent and adjoining portion of Surrey.—Ent. mon. Mag., **34**, pp. 142-149.
- BRADLEY, J. D. (1950). On the occurrence of *Tinea columbariella* Wocke (Lep. Tineidae) in England, with a description of the species.—Entomologist, **83**, pp. 169-172.
- BRADLEY, R. C. (1895). Notes on *Tinea pallescentella*.—Ent. mon. Mag., **31**, pp. 96-97.
- BRÈTHES, J. (1918). La polilla de los graneros.—An. Soc. rur. argent., **52**, pp. 339-342.
- BRÈTHES, J. (1920). Insectos útiles y dañinos de Rio Grande do Sul y de La Plata.—An. Soc. rur. argent., **54**, pp. 281-290.
- BRITTON, W. E. (1918). Seventeenth report of the State Entomologist of Connecticut for the year 1917.—Bull. Conn. agric. Exp. Sta., no. 203, pp. 231-370.
- BRUNETEAU, J. (1930). Les teignes des vêtements.—Rev. Zool. agric., **29**, pp. 149-159.
- BUGDANOV, G. B. (1932). Die Maisschädiger auf dem Territorium des Autonomen Gebiets Inguschien. [In Russian with German summary.].—Izv. Ingushsk. nauch.-issled. Inst., **4**, pp. 93-106.
- BURGESS, R. & POOLE, E. J. (1931). Observations on the susceptibility of animal fibres to damage by the larvae of two species of clothes moth, *Tineola biselliella* Hummel and *Tinea pellionella* L.—J. Text. Inst., **22**, pp. T141-T157.
- BURKS, B. D. (1943). The North American parasitic wasps of the genus *Tetrastichus*—a contribution to biological control of insect pests.—Proc. U.S. nat. Mus., **93**, pp. 505-608.
- BUSCK, A. (1910). Notes on a horn-feeding Lepidopterous larva from Africa.—Smithson. misc. Coll., **56**, pp. 1-2.
- BUSCK, A. (1934). Microlepidoptera of Cuba.—Ent. Amer., **13**, pp. 151-203.

- BUSNEL, R. G. & DRILHON, A. (1943). Présence de riboflavin (vitamine B₂) chez un insecte, *Tineola bisselliella* Hum., alimenté avec un régime privé de cette substance.—C. R. Acad. Sci., Paris, **216**, pp. 213–214.
- BUSVINE, J. [R.] (1951). Insects and hygiene. The biology and control of insect pests of medical and domestic importance in Britain.—482 pp. London, Methuen.
- BUXTON, P. A. (1914). Habit of *Tinea rusticella*.—Ent. Rec., **26**, p. 143.
- CAMPBELL, F. L. & MOULTON, F. R. Ed. (1943). Laboratory procedures in studies of the chemical control of insects.—Publ. Amer. Ass. Advanc. Sci., no. 20, 206 pp.
- CANDURA, G. S. (1937). Studi sugli insetti dannosi ai semi e ai viveri nella Venezia Tridentina. I. Comportamento biologico della *Plodia interpunctella* Hb.—Studi trentini, Sci. nat., **18**, pp. 263–315.
- CANDURA, G. S. (1950). Reperti sulla *Sitotroga cerealella* Oliv. nell'Italia settentrionale e su altre tignole dei viveri.—Boll. Zool. agr. Bâchic., **16**, pp. 99–146.
- CARR, J. W. (1939). *Lycaenopsis argiolus*, *Catocala nupta* and other Lepidoptera in Nottinghamshire.—Entomologist, **72**, pp. 86–88.
- CHEEMA, P. S. (1956). Studies on the bionomics of the Case-bearing Clothes Moth, *Tinea pellionella* (L.).—Bull. ent. Res., **47**, pp. 167–182.
- CHISWELL, J. R. (1955). On the last instar larva of *Tipula livida* van der Wulp (Diptera, Tipulidae) with notes on the fronto-clypeal region of larval Tipulinae and caterpillars.—Proc. R. ent. Soc. Lond., (A) **30**, pp. 127–136.
- CHRÉTIEN, P. (1917). Contribution à la connaissance des Lépidoptères du Nord de l'Afrique. Notes biologiques et critiques.—Ann. Soc. ent. Fr. **82**, pp. 369–502.
- CLARK, A. F. (1929). Insects affecting opossum-skins in New Zealand.—N. Z. J. Agric., **39**, pp. 260–261.
- CLUTTERBUCK, C. G. (1925). Lepidoptera in Gloucestershire, etc., in 1923.—Entomologist, **58**, pp. 129–131.
- COLMAN, W. (1932a). A cage for clothes moth larvae.—J. econ. Ent., **25**, p. 1108.
- COLMAN, W. (1932b). Effect of yeast on clothes moth larvae.—J. econ. Ent., **25**, p. 1242.
- COLMAN, W. (1940). Minimum size of openings through which clothes moth larvae can pass.—J. econ. Ent., **33**, p. 582.
- CORBET, A. S. (1945). Observations on species of Lepidoptera infesting stored products. XIV. *Leucania zae* (Dup.) (Agrotidae) and *Setomorpha rutella* Zeller (Tinaeidae) found on ships in London docks.—Entomologist, **78**, p. 88.
- CORBET, A. S. & TAMS, W. H. T. (1943a). Keys for the identification of the Lepidoptera infesting stored food products.—Proc. zool. Soc. Lond., (B) **113**, pp. 55–148.
- CORBET, A. S. & TAMS, W. H. T. (1943b). Observations on species of Lepidoptera infesting stored products. VII. *Euchromius californicalis* (Pack.), a species distinct from *E. ocella* (Haw.) (Pyralidae: Crambinae). VIII. *Trichophaga tapetzella* (L.) and allied species (Tinaeidae; Tinaeinae).—Entomologist, **76**, pp. 129–132.

- COTTON, R. T. & GOOD, N. E. (1937). Annotated list of the insects and mites associated with stored grain and cereal products, and of their arthropod parasites and predators.—Misc. Publ. U. S. Dep. Agric., no. 258, 81 pp.
- COX, A. J. (1944). Insecticide testing. A review of test procedure for evaluating household insecticides for use in the control of flies, clothes moths, roaches and rodents.—Soap & sanit. Chem., **20**, no. 6 pp. 114–117, 149; no. 7 pp. 123, 125, 129.
- CROWELL, M. F. & McCAY, C. M. (1937). Nutritional studies of the Webbing Clothes Moth *Tineola bisselliella* Hum.—Physiol. Zool., **10**, pp. 368–372.
- CURTIS, W. P. (1932). Further notes on the ravages of *Trichophaga tapetiella* and *Endrosis lactella*.—Ent. mon. Mag., **68**, pp. 166–167.
- CURWEN [B. S.]. (1931). [Report on *Tineola bisselliella* attacking telephone exchange wiring.]—Entomologist, **64**, p. 143.
- DAMPF, A. (1910). Zur Kenntnis gehäusetragender Lepidopterenlarven.—Zool. Jb. (Suppl.), **12**, pp. 513–608.
- DAVIDS, N. J. (1869). *Tinea pelliionella* feeding on cobwebs.—Ent. mon. Mag., **6**, p. 41.
- DAVIDSON, J. (1932). Insects observed on crops in South Australia during the period June, 1930, to June, 1932.—J. Dep. Agric. S. Aust., **36**, pp. 283–286.
- DAY, M. F. (1949). The distribution of alkaline phosphatase in insects.—Aust. J. sci. Res., (B) **2**, pp. 31–41.
- DAY, M. F. (1951a). Studies on the digestion of wool by insects. I. Microscopy of digestion of wool by clothes moth larvae (*Tineola bisselliella* Humm.).—Aust. J. sci. Res., (B) **4**, pp. 42–48.
- DAY, M. F. (1951b). Studies on the digestion of wool by insects. III. A comparison between the tracheation of the midgut of *Tineola* larvae and that of other insect tissues.—Aust. J. sci. Res., (B) **4**, pp. 64–74.
- * DELLA BEFFA, G. (1935). Insetti osservati nella frutta e negli ortaggi dei mercati di Torino.—Dif. Piante Mal. Parass., **12**, pp. 77–85. (Rev. appl. Ent., (A) **23**, p. 706.)
- DIAKONOFF, A. (1938). Indo-Malayan and Papuan Microlepidoptera. 1. Notes on the Tropical Tobacco Moth, *Setomorpha rutella* Zeller (Tineidae).—Treubia, **16**, pp. 399–414.
- DINGLER, M. (1928). Merkwürdiges Auftreten einiger Hausschädlinge.—Anz. Schädlingssk., **4**, pp. 124–125.
- DONER, M. H. & THOMSEN, E. G. (1943). Clothes moths and their practical control.—Soap & sanit. Chem., **19**, no. 10 pp. 102–105, 123.
- DUMONT, C. (1930). Contribution à l'étude des Lépidoptères du nord de l'Afrique. Sur *Morophaga morella* Dup. (Lep. Tineinae); description d'une forme nouvelle, ses premiers états, son éthologie.—Bull. Soc. ent. Fr., **1930**, pp. 286–292.
- DUSPIVA, F. (1936). Beiträge zur enzymatischen Histochemie. XXI. Die proteolytischen Enzyme der Kleider- und Wachsmottenraupen.—C. R. Lab. Carlsberg, Sér. chem., **21**, pp. 177–202.
- DUSPIVA, F. & LINDERSTRØM-LANG, K. (1935). Die Keratinverdauung der Larven von *Tineola bisselliella*.—Verh. dtsh. zool. Ges., **37**, pp. 126–131.
- EALLES, C. (1872). *Tinea pallescentella* bred from a dead cat at South Shields.—Ent. mon. Mag., **8**, pp. 209–210.

- EWING, H. E. (1914). The Common Red Spider or Spider Mite.—Bull. Ore. agric. Exp. Sta., no. 121, 95 pp.
- FALCOZ, L. (1925). Observations biologiques sur divers insectes des environs de Vienne en Dauphiné (3^e note).—Bull. Soc. ent. Fr., **1924**, pp. 221–224.
- FALCOZ, L. (1926). Observations biologiques sur divers insectes des environs de Vienne en Dauphiné (4^e note).—Bull. Soc. ent. Fr., **1926**, pp. 130–134.
- FALLIS, A. M. (1942). The life cycle of *Apanteles carpatus* (Say) (Hymenoptera: Braconidae), a parasite of the Webbing Clothes Moth, *Tineola bisselliella* Hum.—Canad. J. Res., (D) **20**, pp. 13–19.
- FARREN, W. (1886). Tineae taken near Cambridge.—Entomologist, **19**, pp. 78–83.
- FELT, E. P. (1915). Twenty-ninth report of the State Entomologist, 1913.—Bull. N. Y. St. Mus., no. 175, 257 pp.
- FERRIÈRE, C. (1941). Les parasites de la teigne des vêtements.—Mitt. schweiz. ent. Ges., **18**, pp. 374–377.
- FISHER, R. C. (1942). *Tineola biselliella* Hummel, the common clothes moth, in dried blood albumen.—Ent. mon. Mag., **78**, p. 103.
- FLETCHER, J. (1893). Clothes moths.—Rep. ent. Soc. Ont., **23**, pp. 53–58.
- FLETCHER, T. B. (1916). One hundred notes on Indian insects.—Bull. agric. Res. Inst. Pusa, no. 59, 39 pp.
- FLETCHER, T. B. (1920). Life-histories of Indian insects. Microlepidoptera. i–ix.—Mem. Dep. Agric. India., Ent. Ser. **6**, 217 pp.
- FORBES, W. T. M. (1923). The Lepidoptera of New York and neighboring states. Primitive forms, Microlepidoptera, Pyraloids, Bombyces.—Mem. Cornell agric. Exp. Sta., no. 68, 729 pp.
- FORBES, W. T. M. (1933). Two wasp-guests from Puerto Rico (Microlepidoptera).—Psyche, **40**, pp. 89–93.
- FORD, L. T. (1931). Moths in stables.—Entomologist, **64**, p. 259.
- FRAENKEL, G. & BLEWETT, M. (1946). The dietetics of the clothes moth, *Tineola bisselliella* Hum.—J. exp. Biol., **22**, pp. 156–161.
- FRICKHINGER, H. W. (1920). Die Kleidermotte (*Tineola biselliella* Hummel) als Schädling in zoologischen Sammlungen.—Z. angew. Ent., **6**, pp. 400–404.
- FROHAWK, F. W. (1887). *Tineola biselliella*, longevity of larva of.—Entomologist, **20**, p. 233.
- FRYER, J. C. F. (1930). Species of *Tinea* bred from a fungus.—Ent. mon. Mag., **66**, p. 259.
- FRYER, J. C. F. (1932). *Trichophaga tapetiella* Linn. and *Endrosis lactella* Schiff.—Ent. mon. Mag., **68**, pp. 137–138.
- GATER, B. A. R. (1925). Notes on miscellaneous insects in 1924.—Malay. agric. J., **13**, pp. 160–167.
- GAVALOV, I. (1927). Some injurious insects observed in the Crimea in 1922–25. [In Russian.]—Acta Soc. ent. stauropol., **3**, pp. 3–11.
- GEIGER, W. B., KOBAYASHI, F. F. & HARRIS, M. (1942). Chemically modified wools of enhanced stability.—Text. Res., **13**, no. 1 pp. 21–36.
- GEIGER, W. B., PATTERSON, W. I., MIZELL, L. R. & HARRIS, M. (1941). Nature of the resistance of wool to digestion by enzymes.—J. Res. nat. Bur. Stand., **27**, pp. 459–468.

- GEIGY, R. & ZINKERNAGEL, R. (1941). Beobachtungen beim Aufbau einer technischen Grosszucht der Kleidermotte (*Tineola biselliella*).—Mitt. schweiz. ent. Ges., **18**, pp. 213–232.
- GÖSSWALD, K. (1937). Methoden zur Prüfung von Pflanzen- und Vorratsschuttmitteln. XXXI. Methoden zur Dauermassenzucht der Kleidermotte *Tineola biselliella* Hum.—Mitt. biol. Reichsanst., no. 55, pp. 205–208.
- GRAY, H. E. (1935). Some stored product pests in Canada with special reference to the Hairy Spider Beetle *Ptinus villiger* Reit.—Rep. ent. Soc. Ont., **65**, pp. 59–68.
- GRISWOLD, G. H. (1931). On the length of the adult life in the Webbing Clothes Moth, *Tineola bisselliella* Hum.—Ann. ent. Soc. Amer., **24**, pp. 761–764.
- GRISWOLD, G. H. (1933). Fish meal as a food for clothes moths.—J. econ. Ent., **26**, pp. 720–722.
- GRISWOLD, G. H. (1934). Fish meal as a food for clothes moths—supplementary note.—J. econ. Ent., **27**, p. 862.
- GRISWOLD, G. H. (1944). Studies on the biology of the Webbing Clothes Moth (*Tineola bisselliella* Hum.).—Mem. Cornell agric. Exp. Sta., no. 262, 59 pp.
- GRISWOLD, G. H. & CROWELL, M. F. (1936). The effect of humidity on the development of the Webbing Clothes Moth (*Tineola bisselliella* Hum.).—Ecology, **17**, pp. 241–250.
- HANKE, K. (1931). Ein gefährlicher Vorratsschädling: die Kornmotte.—Kranke Pflanze, **8**, pp. 148–150.
- HARGREAVES, H. (1927). Annual report of the Government Entomologist.—Rep. Dep. Agric. Uganda, 1926, pp. 24–27.
- HARTLEY, R. S., ELSWORTH, F. F. & BARRITT, J. (1943). The mothproofing of wool.—J. Soc. Dy. Col., **59**, pp. 266–271.
- HARTMANN, A. (1879). Die Kleinschmetterlinge des Europäischen Faunengebietes.—Mitt. münch. ent. Ver., **3**, pp. 143–200.
- HASE, A. (1937). Neue Beobachtungen über die Männchen und Weibchen der Schlupfwespe *Nemeritis canescens* (Hymenoptera: Ichneumonidae).—Arb. morph. taxon. Ent., **4**, pp. 47–61.
- HASE, A. (1942). Köderungsversuche mit Kleidermotten.—Z. angew. Ent., **28**, pp. 550–570.
- HAYDAK, M. H. (1947). Rearing clothes moth and Black Carpet Beetle in the laboratory.—J. econ. Ent., **40**, pp. 279–280.
- HERFS, A. (1926). Oekologische Untersuchungen an *Pediculoides ventricosus* (Newp.) Berl.—Zoologica, Stuttgart, **28**, Lief. 2, Heft 74, pp. 1–68.
- HERRICK, G. W. (1933). An unusual invasion of the clothes moth, *Tineola bisselliella* (Lepid.: Tineidae).—Ent. News, **44**, pp. 99–101.
- HESSE, E. (1923). Zur Entwicklung von *Tinea lapella* Hb.—Z. wiss. InsektBiol., **18**, p. 301.
- HINTON, H. E. (1943). The larvae of the Lepidoptera associated with stored products.—Bull. ent. Res., **34**, pp. 163–212.
- HINTON, H. E. (1946). On the homology and nomenclature of the setae of Lepidopterous larvae, with some notes on the phylogeny of the Lepidoptera.—Trans. R. ent. Soc. Lond., **97**, pp. 1–37.

- HINTON, H. E. (1948). The dorsal cranial areas of caterpillars.—Ann. Mag. nat. Hist., (11) **14**, pp. 843–852.
- HINTON, H. E. (1953). Digestion of keratin.—Sci. Progr., **41**, pp. 674–682.
- HINTON, H. E. (1955). On the taxonomic position of the Acrolophinae, with a description of the larva of *Acrolophus rupestris* Walsingham (Lepidoptera: Tineidae).—Trans. R. ent. Soc. Lond., **107**, pp. 227–231.
- HINTON, H. E. & CORBET, A. S. (1955). Common insect pests of stored food products. A guide to their identification.—Econ. Ser. Brit. Mus. (nat. Hist.), no. 15 (3rd edn.), 61 pp.
- HINTON, H. E. & GREENSLADE, R. M. (1943). Observations on species of Lepidoptera infesting stored products. XI. Notes on some moths found in bird guano.—Entomologist, **76**, pp. 182–184.
- HOLLANDE, A. C. & CORDEBARD, H. (1926). Notes chimiques et physiologiques se rapportant aux excréments de la teigne du crin (*Tinella biselliella* Hummel; syn. *crinella* Treitsche-Duponchel).—Bull. Soc. Chim. biol., **8**, pp. 631–635.
- HOWARD, L. O. & MARLATT, C. L. (1896). The principal household insects of the United States.—Bull. U. S. Bur. Ent., (N.S.) no. 4, 130 pp.
- HOWE, R. (1940). New records of insects in grain stores.—Ent. mon. Mag., **76**, pp. 73–75.
- ILLINGWORTH, J. F. (1917). Webbing Clothes Moth predaceous.—Proc. Hawaii. ent. Soc., **3**, p. 274.
- JENKINS, C. F. H. (1944). Clothes moths and carpet beetles.—J. Dep. Agric. W. Aust., (2) **21**, pp. 51–57.
- JENSEN [D. D.]. (1945). *Trichophaga tapetzella* (Linn.).—Proc. Hawaii. ent. Soc., **12**, pp. 226–227.
- JENSEN, H. (1917). *Lasioderma* en tabaksmot.—Meded. proefst. vorstenl. Tabak, no. 30, 29 pp.
- * JENSEN [H.]. (1921). Ziekten Tabak, pp. 113–118. (Cited in Diakonoff, 1938.)
- DE JOANNIS, J. (1899). Note sur quelques Microlépidoptères dont les chenilles se nourrissent de poils d'animaux.—Bull. Soc. ent. Fr., **1899**, pp. 248–250.
- DE JOANNIS, J. (1917). Un nouveau méfait de *Tinea granella* L. (Lep. Tineidae).—Bull. Soc. ent. Fr., **1917**, pp. 220–221.
- JORDAN, R. C. R. (1889). *Tinea pallescentella* in Birmingham.—Ent. mon. Mag., **25**, p. 213.
- KANE, W. F. de Vismes. (1900). A catalogue of the Lepidoptera of Ireland.—Entomologist, **33**, pp. 125–127.
- KEMPER, H. (1934). Ueber Hausmottenbekämpfung.—Z. GesundhTech. Städtehyg., **26**, pp. 317–330.
- KEMPER, H. (1935). Die Pelz- und Textilschädlinge und ihre Bekämpfung.—Kleintier u. Pelzt., **11**, pp. 123–187.
- KEMPER, H. (1936). Ueber die Anfälligkeit verschiedener Pelzsorten gegenüber Mottenfrass.—Anz. Schädlingk., **12**, pp. 1–6.
- KEUCHENIUS, P. E. (1917). Waarnemingen over ziekten en plagen bij tabak (derde serie).—Meded. besoek. Proefst., no. 26, 56 pp.

- * KNABEN, N. (1945). Beretning om en del Lepidoptera-arter, nye for Norges fauna. Beskrivelse av *Tinea pallescentella* Stt. f. *semilineatella* n. f.—Bergens Mus. Aarb., **1**, no. 2, 12 pp. [Also in Naturv. Rekke, **1946**, no. 2 pp. 1-12.]
- * KRASIL'SHCHIK, I. M. (1915). On the control of *Calandra granaria* L. [In Russian.]—20 pp. Kishinev, Bio-ent. Sta. Bessarab. Guvernisk. Zemst. (R.A.E., (A) **5**, p. 253.)
- * KRAUSE, A. (1916). *Tinea cloacella* injurious to dried edible mushrooms.—Int. Rev. Sci. Pract. Agric., **7**, p. 623. (R.A.E., (A) **4**, p. 426.)
- KUWAYAMA, S. (1928). The principal insect pests of the rice plant in Hokkaido. [In Japanese.]—Bull. Hokkaido agric. Exp. Sta., no. 47, 107 pp.
- LACK, D. (1932). Further notes on insects from St. Kilda in 1931.—Ent. mon. Mag., **68**, pp. 139-145.
- LAING, F. (1932). *Borkhausenia pseudospretella* and other house moths.—Ent. mon. Mag., **68**, pp. 77-80.
- LEFROY, H. M. (1909). Indian insect life.—786 pp. Calcutta, Thacker & Spink.
- LEHMENSICK, R. & LIEBERS, R. (1937). Die Oberflächenstruktur von Motteneiern als Bestimmungsmerkmal.—Z. angew. Ent., **24**, pp. 436-447.
- LELEUP, N. (1947). Contribution à l'étude des Arthropodes nidicoles et micro-cavernicoles de Belgique.—Bull. Ann. Soc. ent. Belg., **83**, pp. 304-343.
- LESSER, M. A. (1949). Moth products. Part II.—Soap & sanit. Chem., **25**, no. 4 pp. 133, 135, 137, 149, 155.
- LINDERSTRØM-LANG, K. & DUSPIVA, F. (1936). The digestion of keratin by the larvae of the clothes moth (*Tineola biselliella* Humm.).—C. R. Lab. Carlsberg, Sér. chem., **21**, pp. 53-83.
- LINSLEY, E. G. (1944). Natural sources, habits, and reservoirs of insects associated with stored food products.—Hilgardia, **16**, pp. 187-224.
- LINSLEY, E. G. (1946). Some ecological factors influencing the control of carpet beetles and clothes moths.—Pests, **14**, no. 7 pp. 10, 12, 14, 16, 18.
- LINSLEY, E. G. & MACSWAIN, J. W. (1942a). Bionomics of the Meloid genus *Hornia* (Coleoptera).—Univ. Calif. Publ. Ent., **7**, pp. 189-205.
- LINSLEY, E. G. & MACSWAIN, J. W. (1942b). The parasites, predators and inquiline associates of *Anthophora linsleyi*.—Amer. Midl. Nat., **27**, pp. 402-417.
- LOTMAR, R. (1941a). Das Mitteldarmepithel der Raupe von *Tineola biselliella* (Kleidermotte), insbesondere sein Verhalten während der Häutungen. Anhang: *Tineola biselliella* als Wirtstier einer Mikrosporidie (Gattung *Nosema*?).—Mitt. schweiz. ent. Ges., **18**, pp. 233-248.
- LOTMAR, R. (1941b). Ueber eine Mikrosporidieninfektion (Gattung *Nosema*) bei der Kleidermotte, *Tineola biselliella*.—Mitt. schweiz. ent. Ges., **18**, pp. 361-371.
- LOTMAR, R. (1941c). Die Polyederkrankheit der Kleidermotte (*Tineola biselliella*).—Mitt. schweiz. ent. Ges., **18**, pp. 372-373.
- MCATEE, W. L. (1929). Further notes on insect inhabitants of bird houses.—Proc. ent. Soc. Wash., **31**, pp. 105-111.
- MCCORQUODALE, W. H. (1898). Horn feeding larvae.—Nature, Lond., **58**, pp. 140-141.
- MACHIN, W. (1870). Micro-lepidoptera in the City.—Entomologist, **5**, p. 32.

- MADEL, W. (1939). Drogenschädlinge.—Verh. 7. int. Kongr. Ent. Berlin 1938, **4**, pp. 2856–2862.
- MALLIS, A. (1954). Handbook of pest control. The behavior, life history, and control of household pests.—2nd edn., 1068 pp. New York, MacNair-Dorland.
- MANSBRIDGE, G. H. (1936). A note on the resistance to prolonged cold of some insect pests of stored products.—Proc. R. ent. Soc. Lond., (A) **11**, pp. 83–86.
- MANSBRIDGE [W.]. (1891). [*Tineola biselliella* feeding in fish guano.]—Proc. S. Lond. ent. nat. Hist. Soc., **1890–91**, pp. 19–20, 149.
- MARLATT, C. L. (1915). The true clothes moths.—Fmrs' Bull. U. S. Dep. Agric., no. 659, 8 pp.
- MASON, H. C. (1948). *Chremylus rubiginosus* (Nees), a Braconid parasite of the Casemaking Clothes Moth.—Ann. ent. Soc. Amer., **41**, pp. 28–40.
- MATHLEIN, R. (1941a). Undersökningar rörande förrådskadadjur. II. Kornmalarna, *Tinea secalella* Zacher och *Tinea granella* L.—Medd. Växtskyddsanst., no. 34, 56 pp.
- MATHLEIN, R. (1941b). Ett bekämpningsförsök mot kornmal.—Växtskyddsnotiser, **1941**, no. 5 pp. 75–77.
- MELDOLA, R. (1897). [Exhibit of *Tinea biselliella* found infesting bristles.]—Entomologist, **30**, p. 21.
- MELLANBY, K. (1934). Effects of temperature and humidity on the clothes moth larva, *Tineola biselliella* Hum. (Lepidoptera).—Ann. appl. Biol., **21**, pp. 476–482.
- MELLANBY, K. (1936). Humidity and insect metabolism.—Nature, Lond., **138**, pp. 124–125.
- MEYRICK, E. (1928). A revised handbook of British Lepidoptera.—914 pp. London, Watkins & Doncaster.
- MEYRICK, E. (1939). New Microlepidoptera, with notes on others.—Trans. R. ent. Soc. Lond., **89**, pp. 47–62.
- MILLER, L. W. (1948). Insect pests of fabrics.—Tasm. J. Agric., **19**, pp. 96–100.
- MILUM, V. G. (1953). *Tinea fuscipunctella* associated with *Tyroglyphus lintneri*.—J. econ. Ent., **46**, p. 527.
- MITTERBERGER [K.]. (1911). Beitrag zur Kenntnis der Lebensweise der Raupe von *Scardia boletella* F.—Ent. Jb., **20**, pp. 126–128.
- MONCRIEFF, R. W. (1950). Mothproofing.—200 pp. London, L. Hill.
- MORLEY, B. (1915). A year's scientific work in Yorkshire. Entomological section. Lepidoptera.—Naturalist, Lond., no. 696, pp. 40–41.
- * MORLEY, C. (1930). Clothes moths' parasite.—Trans. Suffolk Nat. Soc., **1**, p. 101.
- MORLEY, C. (1935). A beech-tree's insects and their parasites.—Ent. mon. Mag., **71**, pp. 90–91.
- MORLEY, C. & RAIT-SMITH, W. (1933). The Hymenopterous parasites of the British Lepidoptera.—Trans. R. ent. Soc. Lond., **81**, pp. 133–183.
- MORSTATT, H. (1913). Liste schädlicher Insekten.—Pflanzer, **9**, pp. 288–296.
- MORSTATT, H. (1914). Die Schädlinge der Baumwolle in Deutsch-Ostafrika.—Pflanzer, **10**; Beih. no. 1, 50 pp.

- MUESEBECK, C. F. W. (1920). A revision of the North American species of Ichneumon-flies belonging to the genus *Apanteles*.—Proc. U. S. nat. Mus., **58**, pp. 483–576.
- MYERS, J. G. (1922). Notes on the life-history of *Monopis ethelella* (Newm.) (Tineina, Lepidoptera).—N. Z. J. Sci. Tech., **5**, pp. 208–209.
- NAGAMORI, S. (1925). On an interesting Braconid-fly parasitic of a *Tinea*-moth. —Annot. zool. jap., **10**, pp. 349–354.
- NAGEL, W. (1920). Beitrag zur Biologie der Kleidermotte (*Tineola biselliella*) und ihrer Bekämpfung mittels Cyanwasserstoffs.—Z. angew. Ent., **7**, pp. 164–171.
- NONELL COMAS, J. & BERTRÁN OLIVELLA, A. (1927). Insectos que causan plaga a los cereales en pleno campo o en el granero.—Divulg. Estac. Pat. veg., no. 6, 68 pp.
- NORDBERG, S. (1936). Biologisch-oekologische Untersuchungen über die Vogel-nidicolen.—Acta zool. fenn., **21**, pp. 1–168.
- NOTINI, G. (1939). Klädesmalen.—Medd. Växtskyddsanst., no. 28, 32 pp.
- NURSE, C. G. (1906). Food of *Monopis rusticella*.—Entomologist, **39**, p. 160.
- * OGJEWICZ, B. (1934). Contribution à la connaissance des insectes nuisibles des granges. [In Polish with French summary.]—Trav. Soc. Sci. Lett. Wilno, Cl. math. nat., **8**, pp. 143–146.
- * OSSIPOV, N. (1915). A remedy against the house-moth. Family Tineidae. [In Russian.]—Sadovod, **12**, pp. 897–900. (R.A.E., (A) **4**, p. 60.)
- OTTEN, E. (1941). Ueber Nestparasiten der Mehlschwalbe *Delichon urbica* L. (Hemiptera, Diptera, Aphaniptera, Lepidoptera).—Arb. morph. taxon. Ent., **8**, pp. 90–94.
- PAPPENHEIM, E. (1938). Beitrag zur Kenntnis der Oberflächenstruktur von Motteneiern.—Z. hyg. Zool., **30**, pp. 240–243.
- PATTON, R. L. (1945). Insect damage to nylon.—J. econ. Ent., **38**, pp. 522–523.
- PATTON, W. S. (1931). Insects, ticks, mites and venomous animals of medical and veterinary importance. Part II. Public health.—740 pp. [Liverpool Sch. trop. Med.]
- PAYNE, N. M. (1925). *Pyralis farinalis* Linn. (Lepidoptera)—an Alfalfa Hay Worm in Kansas.—J. econ. Ent., **18**, pp. 224–227.
- PEKLO, J. & ŠATAVA, J. (1950). Fixation of free nitrogen by insects.—Experientia, **6**, pp. 190–192.
- PETERSEN, G. (1953). Taxonomie und Verbreitung der Kornmotten (Lepidoptera: Tineidae).—Beitr. Ent., **3**, pp. 577–600.
- PIERCE, F. N. & METCALFE, J. W. (1934a). *Tinea cloacella* Haw., *T. granella* Linn., *T. ruricolella* Staint., *T. cockylidella* Staint., and *T. personella* sp. nov.—Entomologist, **67**, pp. 217–219.
- PIERCE, F. N. & METCALFE, J. W. (1934b). *Tinea merdella* Zell. and its allies.—Entomologist, **67**, pp. 265–267.
- PLIGINSKIĬ, V. G. (1915). Pests of collections and their control. [In Russian.] —Byull. khark. Obshch. Lyub. Prir., **1915**, no. 3 pp. 73–76.
- VAN POETEREN, N. (1932). Verslag over de werkzaamheden van den Plantenziektenkundigen Dienst in het jaar 1931.—Versl. PlZiekt. Dienst, no. 66, 134 pp.

- VAN POETEREN, N. (1935). Verslag over de werkzaamheden van den Plantenziektenkundigen Dienst in het jaar 1934.—Versl. PlZiekt. Dienst, no. 80, 108 pp.
- PORCHINSKIĬ, I. A. (1913). Insects injurious to grain stores and warehouses. Beetles, moths, mites. [*In Russian.*]—Trud. Byu. Ent., **10**, no. 5, 84 pp.
- POWNING, R. F. (1953). Studies on the digestion of wool by insects. VIII. The significance of certain excretory products of the clothes moth, *Tineola bisselliella*, and the carpet beetle, *Attagenus piceus*.—Aust. J. biol. Sci., **6**, pp. 109–117.
- POWNING, R. F. (1954). A study of cysteine desulphydrase in certain insects.—Aust. J. biol. Sci., **7**, pp. 308–318.
- POWNING, R. F., DAY, M. F. & IRZYKIEWICZ, H. (1951). Studies on the digestion of wool by insects. II. The properties of some insect proteinases.—Aust. J. sci. Res., (B) **4**, pp. 49–63.
- PREVETT, P. F. (1954). Fauna of a dead pheasant in London, S.E. 27.—Ent. mon. Mag., **90**, p. 3.
- PYETT, C. A. (1898). Notes on Lepidoptera in 1897.—Entomologist, **31**, pp. 257–258.
- PYETT, C. A. (1902). Notes on Lepidoptera in Suffolk in 1901.—Entomologist, **35**, pp. 2–7.
- PYETT, C. A. (1903). Lepidoptera in Suffolk, 1902.—Entomologist, **36**, pp. 143–146.
- RAU, P. (1930). Life history notes on the wasp, *Polistes annularis*.—Canad. Ent., **62**, pp. 119–120.
- RAWLE, S. G. (1951). The effects of high temperature on the common clothes moth, *Tineola bisselliella* (Humm.).—Bull. ent. Res., **42**, pp. 29–40.
- REH, L. (1928). Eine Mottenraupe als gefährlicher Bücher-Schädling.—Mitt. Ges. Vorratsschutz, **4**, pp. 35–36.
- RICHARDS, O. W. (1949). Parasitic Hymenoptera found in British houses, warehouses and ships. I: Ichneumonidae.—Proc. R. ent. Soc. Lond., (B) **18**, pp. 19–35.
- RICHARDS, O. W. & HERFORD, G. V. B. (1930). Insects found associated with cacao, spices and dried fruits in London warehouses.—Ann. appl. Biol., **17**, pp. 367–395.
- RITCHIE, A. H. (1935). Report of the Entomologist, 1934.—Rep. Dep. Agric. Tanganyika, 1934, pp. 73–83.
- RODIONOV, Z. S. (1940). The qualitative and quantitative damage caused by grain mites. [*In Russian.*]—Uchen. Zap. mosk. gosud. Univ., (Zool.), no. 42, pp. 141–165.
- ROEBUCK, A. (1937). Notes on the economic zoology of Lincolnshire during 1936.—Trans. Lincs. Nat. Un., **1936**, pp. 112–115.
- ROEPKE [W.]. (1918). Entomologische onderzoekingen.—Meded. Proefst. Mid.-Java, **32**, pp. 13–14.
- ROTH, L. M. & WILLIS, E. R. (1952). Observations on the behavior of the Webbing Clothes Moth.—J. econ. Ent., **45**, pp. 20–25.
- ROTHSCHILD, M. & CLAY, T. (1952). Fleas, flukes and cuckoos. A study of bird parasites.—304 pp. London, Collins.

- RYAN, W. St.-G. [1944]. The inspection of grain elevators during wartime.—28th Rep. Quebec Soc. Prot. Pl., 1936-43, pp. 50-52.
- SACHTLEBEN, H. (1941). Ein neuer Parasit der Kleidermotte: *Meteorus atrator* (Curtis) (Hymenoptera: Braconidae).—Arb. physiol. angew. Ent., **8**, pp. 206-208.
- SCHNEIDER-ORELLI, O. (1913). Ueber wurmstichige Flaschenkorken.—Schweiz. Z. Obst- u. Weinb., **22**, pp. 305-307.
- SCHØYEN, T. H. (1916). Beretning om skadeinsekter og plantesygdommer i land- og havebruket 1915.—pp. 37-92.
- SCHULZE, K. (1941). Massenaufreten der Kornmotte (*Tinea granella* L.) an *Secale cornutum* (Mutterkorn).—Mitt. Ges. Vorratsschutz, **17**, pp. 59-61.
- SCHÜTZE, K. T. (1931). Die Biologie der Kleinschmetterlinge unter besonderer Berücksichtigung ihrer Nährpflanzen und Erscheinungszeiten.—235 pp. Frankfurt-am-Main, Int. ent. Ver.
- * SCHÜTZE, K. T. & ROMAN, A. (1931). Schlupfwespen.—Isis budiss., **12**, repr. 12 pp. (R.A.E., (A) **19**, p. 239.)
- SEIDEL, J. (1930). Beobachtungen an Hausschädlingen.—Mitt. Ges. Vorratsschutz, **6**, pp. 2-9.
- SEYDEL, C. (1938). La teigne des cornes (*Tinea vastella* Zell.).—Bull. Cerc. zool. congol., **15**, (54)-(56).
- SEYRIG, A. (1924). Observations sur la biologie des Ichneumons.—Ann. Soc. ent. Fr., **92** (1923), pp. 345-362.
- SHELYUZHKO, L. A. (1935). A survey of insect pests of *Nicotiana rustica* and cigar tobacco plants. [In Russian.].—Sborn. Rab. ent. Otd. VIMPa, pp. 70-97.
- SHMAL'KO, V. S. (1939). On the elaboration of a local method of eliminating insects. [In Russian.].—Pl. Prot., Leningrad, **18**, pp. 176-181.
- SHORT, J. R. T. (1951). Some aspects of the morphology of the insect head as seen in the Lepidoptera.—Proc. R. ent. Soc. Lond., (A) **26**, pp. 77-88.
- SICH, A. (1903). Assembling of *Tinea cloacella*, Hw.—Ent. Rec., **15**, pp. 289-290.
- SICH [A.]. (1908). [Report on species of Microlepidoptera.].—Proc. S. Lond. ent. nat. Hist. Soc., **1907-08**, p. 61.
- SICH, A. (1909a). House moths.—Proc. S. Lond. ent. nat. Hist. Soc., **1908-09**, pp. 7-10.
- SICH, A. (1909b). Notes on Microlepidoptera of southwest London.—Ent. Rec., **21**, pp. 86-87.
- SICH [A.]. (1909c). [Notes on eleven species of *Tinea*.].—Proc. S. Lond. ent. nat. Hist. Soc., **1908-09**, pp. 53-54.
- SICH, A. (1912). Seasonal notes on Tineina.—Ent. Rec., **24**, pp. 111-112.
- SICH [A.]. (1913). [*Tineola biselliella* in Indian rat-snake's den.].—Entomologist, **46**, p. 296.
- SICH, A. (1915). Seasonal notes.—Ent. Rec., **27**, pp. 68-69.
- SICH, A. (1918). Field notes from Bath, 1918.—Ent. Rec., **30**, pp. 134-136.
- SMART, H. D. (1917). Notes on the Lepidoptera of the British Line in France.—Entomologist, **50**, pp. 277-279.
- SMIT, B. (1931). Insect damage to hides and skins.—Fmg in S. Afr., **1931**, repr. no. 27, 3 pp.

- SMITH, K. M. & XEROS, N. (1954). Electron and light microscope studies of the development of the virus rods of insect polyhedroses.—*Parasitology*, **44**, pp. 71–80.
- SMULYAN, M. T. (1919). Some observations on the Webbing Clothes Moth (*Tineola biselliella* Hum.).—*Psyche*, **26**, pp. 71–73.
- SOUTH, R. (1918). *Scardia boleti* and Coleoptera on a fallen beech tree.—*Entomologist*, **51**, p. 215.
- SPENCER, G. J. (1931). An important breeding place of clothes moths in homes.—*Canad. Ent.*, **63**, pp. 199–200.
- SPULER, A. (1910). Die Schmetterlinge Europas.—3. Aufl., Lief. 38b, pp. 289–523. Stuttgart, Schweizerbart.
- STANTON, H. T. (1881). Notes on the entomology of Portugal. V. Lepidoptera (continued). Micro-lepidoptera (Tineina) . . .—*Ent. mon. Mag.*, **17**, pp. 246–249.
- STAMM, K. (1940). Zur Biologie von *Tinea pallescentella* Stt.—*Ent. Z.*, **54**, pp. 38–39.
- STELLWAAG, F. (1924a). *Tinea cloacella* Hw. und *Tinea granella* L.—*Z. angew. Ent.*, **10**, pp. 181–188.
- STELLWAAG, F. (1924b). Die Tierwelt tiefer Weinkeller.—*Wein u. Rebe*, **1924**, pp. 277–297.
- STICKNEY, F. S., BARNES, D. F. & SIMMONS, P. (1950). Date palm insects in the United States.—*Circ. U.S. Dep. Agric.*, no. 846, 57 pp.
- STRINGER, H. (1943). Observations on species of Lepidoptera infesting stored products. X. *Lindera tessellatella* Blanchard, a Tineid new to Britain.—*Entomologist*, **76**, pp. 177–181.
- SUDEIKIN, G. S. (1913). Pests of agricultural plants in the Government of Voronezh, according to observations made in the year 1912. [*In Russian.*]—68 pp. Voronezh, Guvernsk. Zemst.
- SWENK, M. H. (1922). Insect pests of stored grains and their control.—*Circ. Neb. agric. Exp. Sta.*, no. 15, 14 pp.
- TAKAHASHI, R. (1937). Kurze Uebersicht der gegenwärtigen Kenntnisse über die Vorratsschädlinge auf der Insel Formosa.—*Mitt. Ges. Vorratsschutz*, **13**, pp. 4–6.
- TITSCHACK, E. (1922). Beiträge zu einer Monographie der Kleidermotte, *Tineola biselliella*.—*Z. tech. Biol.*, **10**, repr. 168 pp.
- TITSCHACK, E. (1925). Untersuchungen über den Temperatureinfluss auf die Kleidermotte (*Tineola biselliella* Hum.).—*Z. wiss. Zool.*, **124**, pp. 213–251.
- TITSCHACK, E. (1926a). Ueber die imaginale Lebensdauer der Kleidermotte, *Tineola biselliella* Hum.—*Verh. naturh. Ver. preuss. Rheinl.*, **82** (1925), pp. 330–348.
- TITSCHACK, E. (1926b). Untersuchungen über das Wachstum, den Nahrungsverbrauch und die Eierzeugung. II. *Tineola biselliella* Hum. Gleichzeitig ein Beitrag zur Klärung der Insektenhäutung.—*Z. wiss. Zool.*, **128**, pp. 509–569.
- TITSCHACK, E. (1927). Die Bedeutung der Temperatur für die Haus- und Speicherschädlinge.—*Mitt. Ges. Vorratsschutz*, **3**, pp. 12–14.
- TITSCHACK, E. (1936). Experimentelle Untersuchungen über den Einfluss der Massenzucht auf das Einzeltier.—*Z. angew. Ent.*, **23**, pp. 1–64.

- TOSI, R. (1929). Contributo alla conoscenza di due tignole del grano (*Plodia interpunctella* Hb. e *Tinea granella*).—Boll. Lab. Ent. Bologna, **2**, pp. 292–300.
- TUTT, J. W. (1892). Golden Variety of *Tinea misella*.—Ent. Rec., **3**, p. 178.
- ULTÉE, A. J. [1931]. Verslag over de werkzaamheden van het Proefstation Malang in het jaar 1930.—Meded. Proefst. Malang, no. 80, 51 pp.
- VOLLMER, O. (1931). Kleidermotten als Fresser lebender Zecken.—Z. angew. Ent., **18**, pp. 161–174.
- WAKELY, S. (1935). Notes on Micro-lepidoptera.—Proc. S. Lond. ent. nat. Hist. Soc., **1934–35**, pp. 115–118.
- WALKER jr., F. H. (1944). Life histories and control tests on three insect pests of skins stored in the tannery.—J. Kans. ent. Soc., **17**, pp. 7–14.
- WALSH, G. B. (1929). Unusual foods of *Tinea pellionella* L.—Ent. mon. Mag., **65**, p. 151.
- WALSINGHAM, Lord. (1881). On the Tortricidae, Tineidae, and Pterophoridae of South Africa.—Trans. ent. Soc. Lond., **1881**, pp. 219–288.
- WALSINGHAM, Lord. (1894). Micro-lepidoptera from Norfolk and Scotland; including an addition to the British List.—Ent. mon. Mag., **30**, pp. 50–52.
- WALSINGHAM, Lord. (1907). *Tinea flavescens* Hw. (*nec* Stn.), n. syn., = *Tinea merdella*, Stn. (*nec* Z.).—Ent. mon. Mag., **43**, pp. 265–270.
- WALSINGHAM, Lord. (1908). Microlepidoptera of Tenerife.—Proc. zool. Soc. Lond., **1907**, pp. 911–1034.
- WALSINGHAM, Lord & HAMPSON, Sir G. F. (1896). On moths collected at Aden and in Somaliland.—Proc. zool. Soc. Lond., **1896**, pp. 257–283.
- WATANABE, C. (1932). Notes on Braconidae of Japan. III. *Apanteles*.—Insecta matsum., **7**, pp. 74–102.
- WATERHOUSE, D. F. (1952a). Studies on the digestion of wool by insects. IV. Absorption and elimination of metals by Lepidopterous larvae, with special reference to the clothes moth, *Tineola bisselliella* (Humm.).—Aust. J. sci. Res., (B) **5**, pp. 143–168.
- WATERHOUSE, D. F. (1952b). Studies on the digestion of wool by insects. V. The goblet cells in the midgut of larvae of the clothes moth (*Tineola bisselliella* (Humm.)) and other Lepidoptera.—Aust. J. sci. Res., (B) **5**, pp. 169–177.
- WATERHOUSE, D. F. (1952c). Studies on the digestion of wool by insects. VI. The pH and oxidation-reduction potential of the alimentary canal of the clothes moth larva (*Tineola bisselliella* (Humm.)).—Aust. J. sci. Res., (B) **5**, pp. 178–188.
- WATERHOUSE, D. F. (1952d). Studies on the digestion of wool by insects. VII. Some features of digestion in three species of Dermestid larvae and a comparison with *Tineola* larvae.—Aust. J. sci. Res., (B) **5**, pp. 444–459.
- WATERS, E. G. R. (1928). Tineina in the Oxford District.—Ent. mon. Mag., **64**, pp. 172–178.
- WATSON, J. R. (1939). Control of four household pests.—Pr. Bull. Fla agric. Exp. Sta., no. 536, 2 pp.
- WEISS, H. B. (1919). *Tinea cloacella* Haworth bred from fungi (Lepid.).—Ent. News, **30**, pp. 251–252.

- WHITTLE, F. G. (1899). Lepidoptera near Southend in 1898.—Ent. Rec., **11**, pp. 134–135.
- WILKINSON, D. S. (1934). On some *Apanteles* (Hym., Bracon.).—Stylops, **3**, pp. 145–156.
- WILKINSON, G. (1898). Micro-lepidoptera in Cumberland.—Ent. mon. Mag., **34**, pp. 86–87.
- WILSON, H. F. (1940). Lures and traps to control clothes moths and carpet beetles.—J. econ. Ent., **33**, pp. 651–653.
- WOLFF, M. & KRAUSSE, A. (1922). Die forstlichen Lepidopteren.—337 pp. Jena, Fischer.
- WOLFRAM, R. (1952). Zur Einstäubung von Getreide mit Kontaktinsektiziden.—Anz. Schädlingsk., **25**, pp. 73–75.
- WOODROFFE, G. E. (1950). The identity of the Case-bearing Clothes Moth (Lep., Tineidae).—Ent. mon. Mag., **86**, p. 181.
- WOODROFFE, G. E. (1953). An ecological study of the insects and mites in the nests of certain birds in Britain.—Bull. ent. Res., **44**, pp. 739–772.
- WOODROFFE, G. E. & SOUTHGATE, B. J. (1951a). Birds' nests as a source of domestic pests.—Proc. zool. Soc. Lond., **121**, pp. 55–62.
- WOODROFFE, G. E. & SOUTHGATE, B. J. (1951b). A common host and habitat of *Apanteles carpatus* Say (Hym. Braconidae) in Britain.—Ent. mon. Mag., **87**, p. 171.
- WOODROFFE, G. E. & SOUTHGATE, B. J. (1952). *Monopis crocicapitella* (Clem.) (Lep., Tineidae) infesting felt lagging on a water pipe at Harrow, Middlesex.—Ent. mon. Mag., **88**, p. 288.
- YAMADA, Y. (1938). On the life-history of *Tineola biselliella* Hamps. [*In Japanese.*]—Bochu Kagaku, **2**, pp. 13–16.
- YAMADA, Y. (1940). On *Tinea pellionella* L. [*In Japanese.*]—Bochu Kagaku, **4**, pp. 14–20.
- ZACHER, F. (1917). Notizen über Schädlinge tropischer Kulturen. 10. Aufsatz: Afrikanische Tabakschädlinge.—Tropenpflanzer, **20**, pp. 159–175, 207–222, 259–265.
- ZACHER, F. (1927). Die Vorrats-, Speicher- und Materialschädlinge und ihre Bekämpfung.—366 pp. Berlin, Parey.
- ZACHER, F. (1938). Die Kornmotte und die Roggenmotte.—Mitt. Ges. Vorratsschutz, **14**, pp. 65–70.
- ZACHER, F. (1939). Bemerkenswerte Fälle des Auftretens von Vorratsschädlingen 1937–1938.—Mitt. Ges. Vorratsschutz, **15**, pp. 1–5.
- ZACHER, F. (1941). Beobachtungen über “Kornmotten”.—Z. angew. Ent., **28**, pp. 466–476.
- ZACHER, F. (1942). Beobachtungen über Verbreitung und Auftreten von Vorratsschädlingen und ihren Begleitformen.—Z. hyg. Zool. SchädlBekämpf., **34**, pp. 63–78.
- ZACHER, F. (1951). Die wichtigsten Schädlinge des lagernden Getreides.—Mühle, **39**, repr. 11 pp. (Reprint only seen.)
- * ZAGULYAEV, A. K. (1954). On the biology of the Clothes Moth (*Tineola biselliella* Humm.) and of a new species—the Furniture Moth (*Tineola furciferella* Zagulajev, sp.n.). [*In Russian.*]—Trud. zool. Inst. Akad. Nauk SSSR, **16**, pp. 154–169.

- ZVÊREZOMB-ZUBOVSKIÏ, E. (1917). A few words on insects underneath the floor of grain-stores. [*In Russian.*—Zh. prikl. Ent., **1**, pp. 44–46.
- ZVÊREZOMB-ZUBOVSKIÏ, E. (1918). Review of the pests of agriculture in the province of Don. [*In Russian.*—36 pp. Rostov.
- ZWÖLFER, W. (1928). Einige Beobachtungen über das Auftreten der Kornmotte (*Tineæ granella* L.) an gelagerten Maiskolben.—Mitt. Ges. Vorratsschutz, **4**, pp. 43–45.
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THE CONTROL OF CHAFER GRUBS (*SCHIZONYCHA* SP., COLEOPTERA, MELOLONTHINAE) IN THE SUDAN.

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Chafer larvae of the genus *Schizonycha* are a major pest of *Dolichos lablab* (lubia), a leguminous fodder crop, and of *Sorghum vulgare* (dura), the staple grain crop, in the Sudan Gezira. Although widely distributed in other parts of the country, their status outside the Gezira has not yet been investigated. The effectiveness of γ -BHC seed dressings in controlling larvae attacking the dura has been dealt with by Tarr (1954); the present paper is concerned mainly with the relation of the grubs to lubia, and their control by soil applications of γ BHC.

Melolonthid, Rutelid and Scarabeid grubs are widely distributed and serious pests of crops such as maize, millet, groundnuts and tobacco, in Africa. Although a considerable literature exists on the control of chafer larvae, wireworms and other soil pests, by γ BHC, little has been published on these pests in relation to African crops.

Though this paper deals primarily with the control of the larvae of *Schizonycha* sp., certain notes on their biology, habits, and associations with other insects and crops have been included, even though these latter are somewhat fragmentary and incomplete.

The experimental work was carried out at the Gezira Research Farm, Wad Medani; observations were also made on crops in the Gezira (the irrigated, cotton-growing country situated between the Blue and White Niles south of Khartoum).

The Cultivation of Lubia.

Before dealing with the chafer problem, it is desirable to give, as a background, some details of the growing of lubia: the following brief account therefore outlines the extent and nature of lubia cultivation in the Sudan.

Dolichos lablab is widely cultivated in the northern Sudan in riverain flooded areas and, more extensively, on irrigated land, in the Gezira, White Nile, Blue Nile, and Northern Province. It is not grown in the central and southern rainland areas. The plant itself is a herbaceous twiner with luxuriant foliage and it provides an excellent forage crop which may be grazed *in situ* by cattle, or may be cut, baled, and stored. Occasionally the beans may be gathered for human consumption.

In the irrigated Gezira (the region with which this paper is concerned) a quarter of a million feddans (1 feddan = 1.038 acres) of land are annually cropped to cotton (*Gossypium barbadense*), and a further quarter of a million are sown to dura and lubia. These crops, with fallow land, alternate on an 8-course rotation.* The soil of this region is a heavy clay, markedly alkaline (pH 8 to 9), extremely sticky when wet, hard and cracked when dry.

Lubia is sown on ridges, using the local equivalent of a dibble, during September in the Gezira, and receives a first cut, or grazing, in December or January. In favourable seasons, a good second cut may be obtained some eight weeks or less after the first. Lubia sown in July is capable of outyielding a crop sown in September; usually, however, the former suffers heavily from bacterial

* The complete rotation is: CFFCFDLF; where C = cotton, F = fallow, D = dura, and L = lubia.

wilt, fungal disease (*Cladosporium* sp., *Macrophomina* sp.) and sometimes insect attack (whitefly and thrips, see below). Hence, sowing usually awaits the end of the rains (which appear to favour the dissemination of bacterial wilt, as they do the spread of cotton blackarm, *Xanthomonas malvacearum*) and takes place in September.

Sowing is at the rate of 3 to 5 seeds per plant-hole, with about 15,000 holes to the feddan, using (with resowing) about 28 to 30 lb. of seed per feddan. The seeds are placed at a depth of 5 to 10 cm. from the top of the ridge.

Decrease in Yield of Lubia.

The yields of lubia at the Gezira Research Farm have shown a fairly steady decline since the 1946-47 season, and by 1951 gave rise to serious concern over the future of the crop. The decline is illustrated clearly by the figures in Table I.

TABLE I.

Decline in lubia yields at the Gezira Research Farm, 1946-1953.

Season	1946/47	1947/48	1948/49	1949/50	1950/51	1951/52	1952/53	1953/54 [†]
Mean yield/feddan	7140	4929	4368	5745	2097	1157	1415	5485
Feddans on which mean is based ..	25	30	30	30	40	15	30	25

September sown, first cut only, in kilogrammes of fresh weight per feddan.

The second cut could not be considered as the figures are very incomplete: the crop is frequently grazed after the first cut.

[†] The 1953-54 season marks the stage where all main-crop lubia on the Gezira Research Farm was treated with γ BHC. The improvement in yield is not, however, attributable solely to the insecticide, since the chafer attack was very slight and control plots yielded extremely well. The commercial Gezira crop was good also.

These figures are based on crops sown in mid-September and cut in December. In all cases the lubia was from the fallow-dura-lubia (FDL) phase of the Gezira 8-course rotation. In general, the greatest yield decrease was observed when lubia followed dura (DL), though the cotton-dura-lubia (CDL) 3-course rotation was exceptional in giving good lubia crops. The decline in yield was associated with a marked increase in the dying-off of seedlings and young plants. The possible factors responsible for this destruction included: soil conditions (such as waterlogging or drought), fungal disease, and insect attack. The physical factors would, however, be obviated by good husbandry and correct irrigation, while of the fungal diseases, the only one of importance—*Macrophomina* wilt—is normally a secondary invader and not a primary cause of seedling death. The fact that, in numerous cases, young plants showed obvious signs of physical damage to the rooting system indicated that insect pests were probably the cause of destruction.

The Insect Complex on Lubia.

On the foliage, whiteflies (*Bemisia tabaci* (Gennadius)), thrips (*Hercothrips fumipennis* Bagn. & Cam.) and a Galerucid beetle (*Luperodes quaternus* (Fairm.)) may all be serious pests. The bollworm (*Heliothis armigera* (Hb.)) frequently attacks the fruits, while a Buprestid beetle (*Sphenoptera* sp.) occasionally bores in the stems. None of these pests is, however, abundant during the seedling and early growth stages of the plant; they tend to occur later, in November and December.

Of soil pests, the most important are chafer grubs (*Schizonycha* sp.), and various species of termites. Two common species, which probably attack lubia, are *Odontotermes sudanensis* Sjöst. and *Microtermes thoracalis* Sjöst. Both chafer grubs and termites may occur in the soil around young and mature plants, the grubs predominating. However, as will be shown later, while the chafer grubs tend to be associated with living and dying plants, the termites show a strong preference for dead plants. Such an association has been found with both lubia and groundnuts (*Arachis hypogaea*), and has been taken to indicate that the chafer grub is the primary agent in inflicting damage on the plant, the termite being a secondary invader which extends the region of damage or completes the destruction of dead tissue.

Melolonthinae recorded from the Sudan.

Ten genera of MELOLONTHINAE, with a total of 20 species, have been recorded from the Sudan, seven of these species belonging to the genus *Schizonycha*. Three species (*S. pseudoparvula* Gridelli, *S. squamulata* Brenske, and *Schizonycha* sp.*) have been recorded from the Gezira, but so far as is known, only the last is common and the grubs which attack dura and lubia all appear to belong to this one, undetermined, species.

Larvae of *Schizonycha* sp. have been recorded from crop plants in the Gezira at least as early as 1927. A specimen in the collection of the Entomological Section at Wad Medani was taken from dura roots by Cowland (20.viii.1927); while Bedford reported them on the roots of dura (1936) and lubia (1940). Adults have been bred from larvae attacking cotton roots by A. H. Bedawi (1939-40), and from cotton, lubia and groundnuts by the writer (Jan., Feb., 1953).

Cowland (1933) reported that larvae of *Adoretus rugulosus* Burm. (RUTELINAE) were found feeding on cotton roots in the Gezira. However, there is no record of adults being bred out, and since the adults of this species have been recorded only from vines and roses, it would seem that this determination was tentative and based on the larva. It is not unlikely that the larvae were actually those of *Schizonycha* sp.

The only other plant from which *Schizonycha* sp. larvae have been recorded is an unidentified species—probably *Tephrosia apollinea* (Papilionaceae). Larvae, presumed to be those of *Schizonycha* sp., have been taken from legumes such as *Phaseolus lathyroides*, *Leucaena glauca* and *Clitoria ternatea*, but adult determinations have not been made.

Cultural Control.

In view of the apparent association between heavy chafer-grub attack on lubia and the occurrence of a preceding dura crop, it was suggested that removal of dura stubble (which is normally left in the ground) might influence the chafer-grub attack on the following season's lubia. Observations made at the Gezira Research Farm, however, do not appear to promise any effective control by this means. It should also be noted that ploughing, which is sometimes recommended for combating chafer larvae, does not appear to diminish the incidence of this pest, though no critical observations or experiments have been made. Considering the nearness of pupae to the soil surface during January and February (see later) and their delicate structure, it would seem that a fuller investigation of these methods of control might bring some reward.

The Use of γ BHC for Control of Chafer Larvae.

The effectiveness of γ BHC in controlling chafer larvae has been demonstrated by numerous workers. In general, the rates of application, whether the insecticide

* Mr. R. D. Pope of the Commonwealth Institute of Entomology informs me that this species, common in Africa, cannot yet be named with certainty.

be drilled, broadcast, or applied to the ridge, have been heavy. Hammond (1948), for example, recommended $2\frac{1}{2}$ lb. γ BHC per acre for the control of the June beetle, while many other workers have employed even larger amounts. Schwerdtfeger (1950), however, has successfully used lower doses (the minimum being approximately 200 gm. γ BHC per acre) against larvae of *Melolontha melolontha* (L.). The development of seed dressings has shown that much smaller amounts of γ BHC can give control of wireworms. For example, Floyd (1949) used 57 gm., and Thenard (1951) reported the use of 8 to 16 gm. of γ BHC per acre, in controlling these pests.

The present work shows that small applications of γ BHC—as low as 10 gm. per acre—applied as a soil treatment can give excellent control (as measured by crop yield) of *Schizonychia* sp. larvae on lubia in the Sudan. Tarr (1954), employing γ -BHC seed dressings on dura in the Sudan, has recently obtained such control with rates as low as 2 gm. γ BHC per acre.

The details of experiments, on which the results with lubia are based, are given below. Two field trials were conducted at the Gezira Research Farm, the first in the 1951–52 season, the second in the 1952–53 season.

Field trial I (1951–52).

This trial was conducted on five feddans of lubia, sown 18th September 1951, in an 8-course rotation. Five treatments were employed, each replicated five times in randomised blocks. The rate of application of BHC for each treatment was as follows:

- | | | | | |
|-----------------------|----------|-----------------------|------------|-----|
| (1) Nil—Control | | | | |
| (2) 5 lb. BHC dust * | \equiv | 10.2 gm. γ BHC | per feddan | |
| (3) 10 lb. " " | \equiv | 20.4 " " | " " | " " |
| (4) 20 lb. " " | \equiv | 40.8 " " | " " | " " |
| (5) 0.29 lb. BHC-Hg " | \equiv | 27.0 " " | " " | " " |

The last treatment was an organo-mercurial-BHC seed dressing (containing 20% γ BHC), applied at a rate of 1:100 parts by weight of seed. In treatments 2, 3 and 4, the insecticide was applied with the seed to the hole at the time of sowing, being, in effect, "drilled". Cultivation being non-mechanised, however, the insecticide had to be measured and applied, by hand, by means of small metal spoons. Crude as the method was, it proved easy, quick and accurate enough to employ.

The final assessment of results was made on yields but an estimation of plant damage was carried out six weeks after sowing. Eleven hundred plant-holes were examined in each treatment (220 per replicate), and the number severely damaged or destroyed (*i.e.*, with half or more of all leaves dead) recorded. The figures for damaged and destroyed plant-holes, together with the percentage of undamaged plant-holes, are given in Table II.

TABLE II.
Plant damage in field trial I.

Treatment	1	2	3	4	5
Plant-holes damaged or destroyed (1100 examined per treatment)	440	72	71	53	230
Percentage of undamaged plant-holes ..	60	93.5	93.6	95.2	79.1

Yields from this trial are given in Table III. The approximate correspondence between the plant counts in Table II and the yields are worthy of note.

From the figures in Table III it will be seen that the seed-dressing treatment

* A proprietary material ("Agroside 2") containing 0.45% γ BHC.

(No. 5) gave a yield not differing significantly from that of the control: yields from all other treatments were significantly greater than the control, although not differing from each other.

TABLE III.

Lubia yields from field trial I.
(Fresh weight, in kilogrammes per feddan.)

Treatment	1	2	3	4	5
Yield ..	874	3029	3662	3440	1349

Sig. diff. ($P = 0.05$) = 788; Standard error = ± 263 ;
Coeff. of variation = 23.8%.

A possible explanation* for the low yield obtained with the seed dressing may lie in the behaviour of the seed at germination. Tarr (1954) has obtained satisfactory control of *Schizonycha* on *dura* where the seed coat is hypogeal and numerous adventitious roots are produced early by the young plant. With lubia, the seed coat is epigeal, hence there is danger of much of the seed dressing being removed from the vicinity of the primary root. Further, the rooting system of the young plant, being less abundant than in *dura*, renders lubia more liable to damage.

Detailed phytotoxicity tests were not carried out, but at the rates of application used the danger of toxicity would appear to be negligible, even where mercury was present. Field trials conducted in the 1953-54 season (when the chafer-grub attack was extremely weak) showed that soil applications ("drilling") of up to 80 gm. γ BHC, and organo-mercurial-BHC seed dressings of up to 78 gm. γ BHC per feddan, did not impair the stand or yield of the crop.

The response of the crop to BHC was very striking and could be clearly seen within the first few weeks after sowing. Much of the main-crop lubia grown on the Gezira Research Farm during this season suffered heavy damage from the chafer-grub attack. Two fields, adjacent to the experimental one, which had been severely damaged were completely resown and treated with 40 gm. γ BHC per feddan. The new crop gave a good even stand, though yields were low as a consequence of the late effective sowing date and severe whitefly attack followed by a cold winter also checked growth.

Field trial II (1952-53).

The second trial, conducted in the following season, was again on five feddans. The lay-out was a 3 by 4 factorial design with 3 control plots in each block. The treatments were randomised within 10 replicated blocks, the area of each plot, excluding guard rows, being 1/31 feddan (approximately 10 \times 14 metres). The treatments comprised four rates of application (0, 10, 20 and 40 gm. γ BHC per feddan) and three methods of application ("drilling", "ridging", and "broadcasting"). "Drilling" refers to the deposition of insecticide with the seed, in the holes, as in the previous trial. The term "ridging" is used to indicate that the insecticide was deposited in a strip along the top of the ridge and then covered over with earth. In "broadcasting", the insecticide was distributed as evenly as possible over the plots by means of a bellows duster. The rates of application of insecticide were as follows:

Treatment	Insecticide/feddan †	γ BHC/feddan
2, 3, 4	1.538 kg.	10 gm.
5, 6, 7	3.077 "	20 "
8, 9, 10	6.154 "	40 "

*I am indebted to Mr. H. Ferguson (Chief Plant Physiologist) for initiating this explanation.

† A proprietary material ("Agroicide 3") containing 0.65% γ BHC.

In treatments 2, 3, 4 and 5, 6, 7, the insecticide was mixed with finely sieved dust (obtained from insecticide-free soil) to bring the total up to 6.154 kg. By this means, the rate of application became the same for all treatments, thus easing the practical difficulties of application.

The yield results from this experiment are given in Table IV.

TABLE IV.

Lubia yields from field trial II.
(Fresh weight, in kilogrammes per feddan.)

Rate of application in gm. BHC per feddan	Method of Application		
	"Drilling"	"Ridging"	"Broadcasting"
0	2321		
10	8141	3854	3449
20	8690	6809	2456
40	9303	8952	4353

Sig. diff. ($P = 0.05$) = 1616; Standard error = ± 577 ;
Coeff. of variation = 34.8%.

The increase in yield of BHC-treated plots is again amply demonstrated. The photograph (fig. 1), taken near the completion of the experiment, gives an indication of the very great difference which can exist between control and treated plots.



Fig. 1.—Background plot treated with 40 gm. γ BHC per feddan (1.038 acre), foreground plot untreated. (Metre ruler shows height of treated crop.)

The yield results show that "drilling" is, in general, superior to "ridging" or "broadcasting". With "drilling", as in trial I, there is no significant

difference between the three rate levels, though the small differences which do exist are in accordance with expectation. "Broadcasting" gave uniformly poor results, only at the highest rate (40 gm.) did the yield differ significantly from control.

During the course of the second trial, observations were made on the chafer-grub population in all the treatments. The sampling methods employed, and the results of population counts, are given below.

Sampling.

The distribution of grubs in a field is variable and depends mainly on the location of oviposition. Adequate randomisation with well-replicated small plots will, however, tend to even out the differences due to such variation.

In any infested area within the field, the position of the grubs appears to be influenced largely by the location of the crop plants. A number of observations was made over areas 1 metre square (9 plant-holes of lubia), all the soil being excavated and the position of grubs, relative to plants, recorded. Invariably the grubs were found in close association with the plant roots and not distributed at random in the soil. Lateral (as well as vertical) movement of grubs doubtlessly occurs, but was not detected during these examinations. Further observations, on the depth of grubs in the soil, showed that they do not occur below about two feet (60 cm.). In sampling, therefore, the soil excavation was carried to a depth of two feet and confined to the region immediately around each plant-hole. In any one count, five plant-holes were examined in each plot, giving a total of 50 per treatment. Results of the counts carried out in field trial II are given in Table V.

All soil examinations were made by hand, by Sudanese assistants, and were carried out during the intervals between irrigations when the soil was damp and reasonably friable.

Larval Populations.

The most obvious feature of the figures in Table V is the lack of correspondence with the yield data (Table IV). Only in the case of the first count—and here mainly at the highest concentration (40 gm.)—is there any appreciable reduction (and this only temporary) in the number of larvae. Comparison of treatment counts with controls also reveals the general similarity of the figures.

TABLE V.
Schizonycha sp. larvae from field trial II.
(Larvae per 50 plant-holes of lubia.)

Date	Con- trol	Rate of application in gm. γ BHC/feddan								
		Drilled			Ridged			Broadcast		
		10	20	40	10	20	40	10	20	40
27.x.52 ..	73	61	71	38	61	58	48	75	80	67
23.xi.52 ..	111	111	99	103	97	90	93	106	92	98
7.xii.52 ..	107	88	110	99	95	103	109	104	96	89
21.xii.52 ..	95	80	95	88	119	129	97	113	108	96
Mean ..	97	88	99	92	86	100	97	102	99	88

Each control count consists of the average of 3 sets of plots and the mean the average of 12.

In view of the striking yield response obtained with BHC, it can only be concluded that the insecticide repels the larvae, or in some way prevents feeding, but does not kill them. Such a repellent effect is already well known with wireworms (Jameson, Thomas & Woodward, 1947) and has also been demonstrated for other Melolonthid larvae (*Melolontha hippocastani* F. and *M. melolontha*) by Schwerdtfeger (1950).

Later observations, in March and July 1953, were made on this field. Some overall reduction in population occurred, affecting all treatments equally. In March, pupae were present in addition to larvae, but by July the former were largely replaced by adult beetles. The insecticide does not therefore appear to prevent pupation or adult emergence.

The method of feeding and survival of larvae in treated soil is unknown, but laboratory experiments in which larvae were confined to insecticide-free soil from November onwards, showed that development can, in some cases, be completed in the absence of living plants.

Depth of Larvae and Pupae in the Soil.

Observations on the vertical distribution of larvae and pupae in the soil were carried out, mainly during 1953 and 1954, on dura and lubia. In these observations, soil was removed from around each plant-hole to a depth of 1 metre and the position of larvae and/or pupae recorded in centimetres from the top of the ridge.

Larvae on dura.

Observations on dura were carried out during October and November 1953, in the course of a general survey on *Schizonycha* in the Gezira. Results are given in Table VI.

TABLE VI.

Depth of *Schizonycha* sp. larvae in soil. (Dura: Gezira.)

Depth in cm.	October		November	
	No. of larvae	No. as % of total	No. of larvae	No. as % of total
1-5 ..	0	0	0	0
6-10 ..	9	2.9	4	2.7
11-15 ..	25	8.0	32	21.8
16-20 ..	43	13.8	45	30.6
21-25 ..	42	13.5	28	19.0
26-30 ..	57	18.3	21	14.3
31-35 ..	38	12.2	6	4.1
36-40 ..	39	12.5	8	5.4
41-45 ..	27	8.7	3	2.0
46-50 ..	17	5.4	0	0
51-55 ..	10	3.2	0	0
56-60 ..	5	1.6	0	0

These figures are based on the results of examinations made in three of the Gezira Groups, *viz.*, South, Centre, and Messellemya (see map, fig. 2). They have been arranged in 5-cm. class intervals to show the number of grubs found at each level, in each of the two months.

During October, the mean depth of larvae in the soil was 30.1 cm.; during November it was 21.5 cm. This vertical displacement is common to all the three groups examined, as the means in Table VII show.

TABLE VII.

Mean depth of *Schizonycha* sp. larvae in soil. (Dura: Gezira.)

	October	November
South Group	29.8	24.1
Messellemya Group .. .	32.4	17.2
Centre Group	29.8	21.9
Mean	30.1	21.5

(Measurements in cm. from top of ridge.)

This vertical movement may be connected with the cessation of watering and the drying-out of dura roots. Irrigation ceases during October or November and the plant roots die off from the apex upwards. The upward movement of grubs would then result from keeping pace with the root remains on which they are feeding. On the other hand, the movement may be unconnected with feeding and be related to the approaching onset of pupation, and be governed by other factors. Little is known on the feeding phases of these larvae: in the laboratory they can survive starvation for two months prior to pupating, which suggests that the movement may not be related to feeding.

Larvae and pupae on lubia.

The only detailed counts available for larvae and pupae on lubia in insecticide-free soil were made during January 1954, at the Gezira Research Farm. Results of these counts are given in Table VIII.

TABLE VIII.

Depth of *Schizonycha* sp. larvae and pupae in soil. (Lubia: Gezira Research Farm.)

Depth in cm.	Larvae		Pupae	
	No. of larvae	No. as % of total	No. of pupae	No. as % of total
1-5 ..	2	4.5	10	11.5
6-10 ..	6	13.6	11	12.6
11-15 ..	16	36.4	31	35.6
16-20 ..	7	15.9	19	21.8
21-25 ..	6	13.6	9	10.4
26-30 ..	5	11.4	5	5.8
31-35 ..	0	0	1	1.2
36-40 ..	2	4.5	1	1.2

It will be seen that the range of depth is less than with dura and the mean depth also (17.9 cm. for larvae, 15.3 cm. for pupae) is rather less than that recorded for the latter crop. These differences may be connected with the shallower rooting system of lubia or they may be related to the pre-pupation habits of the larvae. There is as yet insufficient evidence to decide this matter.

Effect of BHC on depth of pupation.

A series of observations, similar to those detailed in the preceding section, were made on the depth of larvae and pupae in soil treated by drilling with 20 gm. γ BHC per feddan. These were again on lubia at the Gezira Research Farm, and were also made during January. A comparison of the figures for pupal depth with those from Table VIII (representing BHC-free soil) is made in Table IX, each set being from a different field.

TABLE IX.

Effect of BHC on depth of pupation in soil. (Lubia: Gezira Research Farm.)

Depth in cm.	Percentage of pupae at each level	
	Soil treated with BHC	Soil untreated
1-5 ..	13.6	11.5
6-10 ..	13.6	12.6
11-15 ..	39.4	35.6
16-20 ..	21.2	21.8
21-25 ..	9.1	10.6
26-30 ..	1.5	5.8
31-35 ..	1.5	1.2
36-40 ..	0	1.2
Mean depth ..	14.1 cm.	15.3 cm.
Number of specimens ..	66	87

The two fields on which these observations were made were adjacent, of equal area, in the same rotation, and were divided into plots within which random samples were taken. The comparison is not, of course, strictly valid, but it does nevertheless appear to indicate that there are no broad differences in pupation depth in BHC-treated and untreated soil.

Distribution of *Schizonycha* sp. Larvae in the Gezira.

During October and November 1952 and 1953, sampling for chafer larvae was carried out in each of the 44 Blocks of the irrigated Gezira Scheme. Lubia was examined during the first year and dura during the second. One hawasha (a

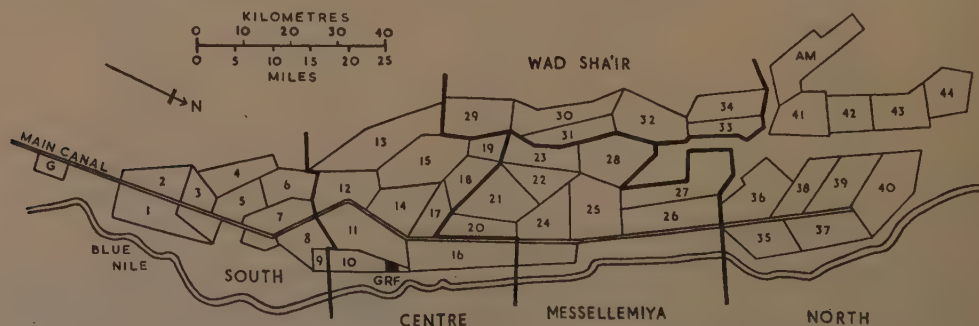


Fig. 2.—The irrigated Gezira Scheme. G = Gondal; G.R.F. = Gezira Research Farm; AM = Abdel Magid. For names of numbered Blocks, see Table X.

10-feddan field) was selected in each Block and 100 plant-holes examined at random within it. Results are shown in Table X; the location of the Blocks can be found on the map (fig. 2).

TABLE X.

Distribution of *Schizonycha* sp. larvae (per 100 plant-holes) on lubia and dura in the Gezira.

Block		Lubia (1952)	Dura (1953)	Block		Lubia (1952)	Dura (1953)
No.	Name			No.	Name		
1	Hag 'Abdullah ..	4	2	23	Wad Husein ..	44	0
2	Fahl ..	20	21	24	Nidyana ..	22	9
3	Ghubshan ..	0	27	25	Wad Sulfab ..	4	13
4	Wad Nu'man ..	57	166	26	Dolga ..	2	0
5	Hosh ..	20	23	27	Istarahna ..	2	5
6	Remitab ..	29	26	28	Rukn ..	11	38
7	Wad el 'Ataya ..	9	31	29	Nuweila ..	0	0
8	Hamad en Nil ..	35	16	30	Futeis ..	0	0
9	Seed Farm ..	0	0	31	'Amara Kasir ..	0	6
10	Barakat ..	14	1	32	Keteir ..	33	0
11	Darwish ..	121	69	33	Turis ..	0	4
12	Kumur ..	22	5	34	Fauwar ..	0	1
13	Radma ..	99	36	35	Umm Degarsi ..	0	0
14	'Abd el Hakim ..	13	4	36	Dubeiba ..	2	0
15	Madina ..	0	18	37	Turabi ..	0	0
16	Taiyiba ..	55	44	38	Mi'eiliq ..	2	0
17	Suleimi ..	24	15	39	Kab el Gidad ..	2	0
18	Tebub ..	31	2	40	La'ota ..	2	2
19	Wad el Burr ..	15	7	41	Abu Gin ..	0	0
20	Galil ..	26	0	42	Guweiz ..	2	0
21	Wad Sa'dullah ..	29	27	43	Sudeira ..	0	0
22	'Abd er Rahman ..	11	1	44	Faragin ..	0	0

Though only a brief survey, the examination does give some indication of the incidence of this pest in various parts of the Gezira Scheme. There is a rough correspondence between the two sets of counts, even though they were made in different seasons and on different crops. In both cases, it is the Centre and South Groups which carry the heaviest infestation. The Messellemiya Group has slightly less than half the infestation of these two, while in the Wad Sha'ir and North Groups, chafer larvae are sparse or absent. No large-scale estimation of lubia damage has been made but it is clear that it is in the South and Centre Groups that heaviest damage is to be expected.

Association of Larvae with Other Crops.

Besides lubia and dura, *Schizonycha* sp. larvae have been found in association with the roots of cotton and groundnuts. The latter crop is very susceptible to attack and several instances of severe damage, both on the Gezira Research Farm and in the southern Gezira, are known. There is no record of severe damage to this crop in the northern Gezira, where—as shown by the distribution figures in the preceding section—the *Schizonycha* population is very low.

Larvae can sometimes be found, in small numbers, in cotton fields and 27.5 and 34 larvae per 100 plant-holes (200 examined in each case) have been recorded in two examinations on cotton from the FFC phase of the 8-course rotation at the Gezira Research Farm. However, so far as is known, there is no serious damage or yield reduction with this crop.

Association of Larvae and Termites.

Chafer larvae and termites occur together in the soil around the crop plants mentioned above, and are particularly evident on groundnuts. Examination of a field of groundnuts for these two pests gave the results shown in Table XI.

TABLE XI.

Chafer larvae and termites associated with groundnuts.

		Dead plants	Living plants
Percentage of plants infested by:—	Chafer larvae	48.9	72.6
	Termites ..	38.6	6.3
Number of chafer larvae per 100 plants		64.3	129.0

Random samples were taken within plots, equal numbers of dead and living plants being examined. It will be seen that there is a definite tendency for the chafer larvae to be associated with living plants, the termites with dead ones; larvae are also more commonly associated with dying plants than are termites. An explanation for this is that the larvae initiate the attack on a plant while the termites follow on as secondary invaders when the plant is dead. Similar behaviour has been noted in other soil insects, *e.g.*, wireworms (Michelmore, 1954).

The Effect of Chafer Control on a Subsequent Crop.

The experiment (field trial I) conducted on lubia in the 1951-52 season was on a field which later, in 1953-54, came under cotton. The yields of the cotton were taken from the same plots as in the original lubia experiment. These yields, together with those of lubia, and the insecticide rates, are given in Table XII.

TABLE XII.

Yields of cotton and lubia from the same treated field, in different seasons.

Treatments (applied 1951)				Lubia ¹ (1951-52)	Cotton ² (1953-54)
1. Control	0 gm. γ BHC	..	..	874	4.92
2. "Drilling"	10 "	..	..	3029	5.83
3. "	20 "	..	..	3662	5.83
4. "	40 "	..	..	3440	5.53
5. Seed dressing	27 "	..	..	1349	5.23
Significant difference				788	0.64
Coeff. of variation				23.8%	8.7%
Standard error				± 263	± 0.21

¹ Lubia yield given in kilogrammes per feddan.

² Cotton yield given in kantars per feddan

(1 kantar = 142 kilogrammes of seed cotton).

Comparison of the two sets of results shows that there is a tendency for the cotton yields to be related to the lubia yields rather than to the insecticide

levels. (This can be shown simply by graphing yields and γ -BHC rates in the treatment order: 1, 2, 3, 5, 4.) Analysis of the data also leads to the same conclusion and it would seem that the increase in cotton yield is attributable largely, if not wholly, to the beneficial effect of the preceding legume crop rather than to the persistence of insecticide with attendant insect control.

A Note on the Biology of *Schizonycha* sp.

The time available for biological study of this pest has been limited, hence the seasonal and life-histories are incompletely known. The few facts which have been elucidated are given below.

The adults appear during the rains, from July to September, and are most active at dusk. They are known to feed on lubia, and probably feed on a number of other plants. Oviposition has not been observed but presumably takes place during the rains: adults are seldom seen, or caught in traps, after September.

Pupation takes place between December and March. The grub forms a smooth-lined earthen cell at a mean depth of 15 cm. in the soil. The adult emerges from the pupa about one month later, but remains quiescent within the cell. In this way it survives the hot dry season during the period April to June. The adult does not finally vacate the soil until July or August, the heavy rains of these months presumably providing the necessary stimulus.

The duration of the life-cycle is unknown but it appears to be in excess of one year. Heavy chafer damage to lubia probably results from heavy oviposition in the preceding dura crop on the same land. Only a portion of the larvae present in the soil during the winter actually pupate; the remainder survive the dry season in the larval state and can be detected in the soil during the whole of this period.

Summary.

Schizonycha larvae, of a species that cannot yet be named with certainty, are a serious pest of "lubia" (*Dolichos lablab*) and "dura" (*Sorghum vulgare*) in the Sudan Gezira. Damage from these grubs has seriously reduced lubia yields at the Gezira Research Farm during the 1946-52 seasons. Soil application of BHC, at rates between 10 and 40 gm. γ isomer per feddan (1.038 acre) give excellent control of this pest on lubia. Application with the seed at the time of sowing (in effect, by drilling) is, in general, more effective than broadcasting or applying the insecticide along the ridges. Seed dressings appear to be ineffective for control, with lubia.

Population estimates show that γ BHC does not kill *Schizonycha* larvae but repels them or prevents feeding. The larvae occur in the soil to a maximum depth of 60 cm., and are concentrated around the plant roots. The mean depth varies with time of year, and probably with type of plant, between 15 and 30 cm. The mean depth of the pupa is 15 cm.; this does not appear to be influenced by BHC.

Larvae are widely distributed in the Gezira but are most abundant in the South and Centre Groups of the Scheme. There is evidence that, where chafer larvae and termites are associated with groundnuts, the chafer larvae are responsible for initiating damage while the termites are secondary invaders. The beneficial effect of a good lubia crop (resulting from BHC application) is reflected in the cotton crop two years later.

Acknowledgements.

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References.

- 25 215 BEDFORD, H. W. [1936]. Entomological Section, Agricultural Research Service. Report . . . 1934/35.—Rep. agric. Res. Serv. Sudan, 1935, pp. 63–96.
- 1 10 BEDFORD, H. W. [1940]. Entomological Section, Agricultural Research Service. Report . . . 1937/38.—Rep. agric. Res. Serv. Sudan, 1938, pp. 50–71.
- 21 582 COWLAND, J. W. [1933]. Gezira Entomological Section, Gezira Agricultural Research Service. Final report on experimental work, 1931/32.—Rep. Gezira agric. Res. Serv. Sudan, 1932, pp. 93–112.
- 38 101 FLOYD, E. H. (1949). Control of the Sand Wireworm in Louisiana.—J. econ. Ent., **42**, pp. 900–903.
- HAMMOND, G. H. (1948). White Grubs.—Process. Publ. Div. Ent. Dep. Agric. Can., no. 88, 4 pp.
- 5 1231 JAMESON, H. R., THOMAS, F. J. D. & WOODWARD, R. C. (1947). The practical control of wireworm by γ -benzene hexachloride ("Gammexane"): comparisons with dichlorodiphenyltrichlorethane (DDT).—Ann. appl. Biol., **34**, pp. 346–356.
- MICHELMORE, A. P. G. (1954). Section of Entomology.—Rec. Dep. Agric. Uganda, no. 3 (1950–52), pp. 39–93.
- 289 SCHWERDTFEGER, F. (1950). Untersuchungen über die Wirkung von Hexamitteln bei der Engerlingsbekämpfung im Forstschutz.—Z. PflKrankh., **57**, pp. 246–272.
- 1 10 2 1 5 TARR, S. A. J. (1954). Control of Cockchafer grubs by seed treatment.—Nature, Lond., **173**, p. 1052.
- THENARD, J. (1951). The production of segmented beet seed.—Plant Prot. Overseas Rev., **2**, no. 4, pp. 23–27.
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SUPERPARASITISM BY *SPALANGIA DROSOPHILAE* ASHM.

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The general biology of *Spalangia drosophilae* Ashm. has already been described (Simmonds, 1952, 1953), as has the type of host preferred by ovipositing females (Simmonds, 1954). The reactions of an ovipositing female to a host which, though otherwise suitable, has already been parasitised by *Spalangia* have now to be considered. Whether an ovipositing parasite can distinguish between a healthy and an already parasitised host has been investigated several times before, e.g., Salt (1934, etc.) using *Trichogramma evanescens* Westw. a parasite of *Sitotroga cerealella* (Ol.), Lloyd (1938) using *Ooencyrtus kuvanae* (How.) a parasite of *Lymantria dispar* (L.), and Lloyd (1940) with *Angitia cerophaga* (Grav.), *Diadromus subtilicornis* (Grav.) and *D. collaris* (Grav.) parasites of *Plutella maculipennis* (Curt.) and Simmonds (1943) using *Nemeritis canescens* (Grav.) a parasite of *Ephestia kuehniella* Zell. From this and other work it has become increasingly evident that the females of a number of parasite species can distinguish already parasitised hosts and refrain to a certain extent from ovipositing in them. It may be reiterated here that the power of distinguishing between an already parasitised and a healthy host is termed "discrimination" and the power to refrain from ovipositing in a parasitised host thus distinguished is termed "restraint".

"Superparasitism" is used with the meaning ascribed to it originally by Smith (1916)—"a superabundance of parasites of a single species attacking an individual host", that is, the condition that occurs when a host receives a greater number of individuals of a single species of parasite than it can nourish to produce normal adults.

It is found that only one adult *Spalangia* can complete its development in a puparium of *Drosophila melanogaster* Mg. and that only one egg is laid at a time by an ovipositing female. If more than one egg is laid in the puparium, the parasite larvae, on coming into contact on the surface of the pupa, attack one another in the first instar, with the result that supernumerary larvae are eliminated. Thus superparasitism represents a waste of parasite eggs, and any avoidance of it potentially increases the numbers of the parasite progeny by eliminating this waste. Observation has shown that the process of oviposition consists of several phases. First there is a minute examination of the host puparium, the surface being tapped carefully with the antennae. This may be followed, presumably if the puparium is found to be suitable, by the stinging of the pupa. When stinging occurs, a tube is sometimes formed round the ovipositor from the host pupa to the outside of the puparium, and through this the adult parasite may feed on the exuding pupal body-fluid. This tube is formed by the coagulation around the ovipositor of host-body fluids seeping from the puncture in the pupa. After stinging, the pupa is paralysed, and this is particularly noticeable in the cessation of the beat of the heart in the mid-dorsal line. Finally, oviposition may take place on the paralysed pupa, but there are always a number of puparia that are attacked and stung only, and in which no eggs are laid. The duration of each of these phases and their relationship to discrimination between unparasitised and parasitised hosts will be discussed later.

Methods.

In order to test the occurrence and extent of discrimination, if any, and restraint exerted by the ovipositing female, and the variation of this complex

[illegible]

with changes in the numbers of hosts available per female, a number of experiments were set up in which ovipositing females were offered a different number of hosts for different lengths of time.

The relationship between the parasite females and their hosts has been expressed throughout as the P/H ratio, and in computing this, both the number of parasites and the length of time for which hosts were exposed to them have been considered. Thus, taking a 24-hour laying period as a unit, a single *Spalangia* female left with 25 hosts for 24 hours gives a P/H ratio of 1/25, and if left for 48 hours, or if two females are left for 24 hours, the P/H ratio is 2/25. This convention is acceptable in view of the fact that the immunity to further attack conferred on a host when it is once parasitised was found to be permanent and not only a temporary effect.

The numbers of hosts used were 25, 10, and 5, and in order to obtain higher P/H ratios, 2 and 5 females per experiment were used. Also, to test the permanence or otherwise of any immunity conferred on the host when it is parasitised, all experiments were repeated, leaving the parasites ovipositing for 24, 48 and 72 hours. Virgin and mated females were tested singly to determine any difference in their behaviour during oviposition. Each experiment was repeated ten times. Thus, 360 different experiments were set up; 25, 10 and 5 puparia, with single mated and unmated females, with 2 and 5 females, left exposed to attack for 24, 48, and 72 hours, involved the use and subsequent minute examination of over 5,000 puparia. The host puparia were 0 to 24 hours old and stuck on paper with water, equidistant $\frac{1}{4}$ in. from each other (fig. 1) to obviate any prolonged searching for a host on the part of the parasite and the consequent effect that this might have on the distribution of eggs.

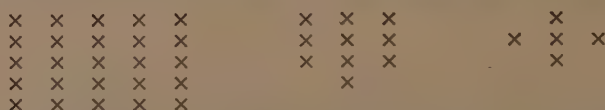


Fig. 1.—Arrangement of host puparia on squared paper in superparasitism experiments.

Each paper bearing puparia was labelled, and placed in a $4\frac{1}{2}$ in. \times 1 in. vial with a cork bearing a muslin-covered damp cotton pad and a split raisin. The appropriate number of ovipositing female *Spalangia* under 3 weeks old were introduced into the vial, and left for the 24, 48, or 72 hour period. After this, each puparium was carefully examined in a drop of water on a slide under the binocular microscope and the number of eggs laid in it, or whether it was stung or unparasitised was noted. This was recorded in the appropriate square on a record sheet duplicating the arrangement of the experiment. Following this examination, the puparium was gently pressed in the drop of water with a coverslip. This showed up the *Spalangia* eggs more clearly, and a second count was made to act as a check on the first. The position on the paper of the puparia in which the eggs were laid being noted, it was possible to see if the position of an individual puparium in the experiment affected its susceptibility to attack.

Analysis of these results showed that the position of any individual puparium in any experiment did not affect its chances of being attacked, and that consequently the results obtained could be treated mathematically with regard to distribution without any modification due to the selection of certain hosts for attack because they occupied a favoured position on the sheet.

It was hoped that the results would provide information on the following points:—

1. The extent, if any, to which the distribution of eggs by the female parasite differs from a random distribution when no prolonged searching for the host occurs.

2. The extent of discrimination, if present, and the powers of restraint possessed by a female allowing her to refrain from ovipositing in a host sensed to be already parasitised.
3. Whether any "immunising" of a host by a single oviposition is permanent or only temporary.
4. Whether mated and virgin females differ in their oviposition behaviour.
5. Whether the limitation of the number of hosts available causes a decrease in the number of eggs produced each day (another effect of restraint).

Results.

The results were assessed by comparing the observed distribution of parasite eggs amongst host puparia with the probable random distribution calculated from Stoy's formula (Salt, 1932):

$$A = N^x C_p \left(\frac{1}{N}\right)^p \left(1 - \frac{1}{N}\right)^{x-p}$$

where A is the number of hosts that receive p eggs, N is the total number of hosts present, x the total number of eggs laid, and ${}^x C_p$ the number of combinations of x eggs taken p at a time.

The result of each experiment is not given individually as the tables would be too extensive, but in Table I are given, for each P/H ratio, two frequency distributions showing the number of hosts receiving different numbers of parasite eggs, in the first of which each of the entries is obtained by adding together the observed values of the corresponding entry in the ten experiments made at that P/H ratio, while in the second it is obtained by addition of the values calculated, in each experiment separately, by Stoy's formula.

In some experiments a few puparia collapsed and decomposed. These were not counted in the experiment and thus the total number of puparia shown in the results of some experiments is slightly lower than the original number used in the experiment.

In the first place, it is evident that the behaviour of the virgin and mated females with regard to egg distribution is similar. At some of the higher P/H ratios the total eggs laid by the virgin females is less than that of the mated females, but these differences are probably fortuitous since the figures for the total eggs laid by virgin and mated females (Table II) indicate no significant difference between them in this respect.

TABLE II.

Oviposition rates of females in superparasitism experiments. Total eggs laid.

Number of hosts	25			10			5		
	24	48	72	24	48	72	24	48	72
Exposure to parasites in hours									
Single mated female	7.4*	7.6*	18.4	6.4*	11.0	12.9	4.8	4.7	4.9
Single unmated female	6.5*	8.3*	15.3	6.5*	8.1	9.1	4.3	4.5	5.8
Two mated females	15.8	17.9	22.9	8.5	11.4	15.7	8.5	9.6	10.8
Average per female	7.9	8.9	11.4	4.2	5.7	6.8	4.2	4.8	5.4
Five mated females	29.6	38.9	38.2	20.9	23.3	24.8	11.8	21.9	23.4
Average per female	5.9	7.8	7.6	4.2	4.7	5.0	2.4	4.4	4.7

* Only individual experiments in which over 5 eggs laid taken into account.

Also, it is obvious that at the lower P/H values there is a high degree of avoidance of superparasitism, and that when the P/H ratio is lower than 3/25 there is very little superparasitism. In individual experiments this avoidance of superparasitism is even more striking, and in one case 21 eggs were laid in 21 hosts without any superparasitism occurring. As the P/H ratio increases, so does the degree of superparasitism, but it is less than would be expected from a random distribution of eggs. Thus the ovipositing females possess powers of discriminating between parasitised and unparasitised hosts, and can to a certain extent exert a restraint and avoid laying in hosts sensed to be parasitised.

In a previous paper (Simmonds, 1943), an analysis has been made of the possible combinations of perfect, imperfect, and lack of discrimination and restraint in a similar case (*Nemeritis canescens* parasitising larvae of *Ephestia kuehniella*) in which one egg is laid at each successful attack on a host capable of supporting only a single parasite larva to maturity. It is unnecessary here to repeat the arguments set forth in that instance, but in the present case it is obvious that the combination in effect is that of perfect discrimination and imperfect restraint, since when hosts are plentiful the ovipositing parasite can distinguish an already parasitised host, refrain from ovipositing in it, and distribute its eggs so that only singly parasitised and unparasitised hosts occur. With increasing P/H ratio, i.e., relative decrease in the number of hosts available, superparasitism occurs, indicating that restraint breaks down. With further increase in P/H ratio this degree of superparasitism increases, indicating a more frequent breakdown of restraint. This is similar to the condition found to exist in *Trichogramma evanescens* (Salt, 1934).

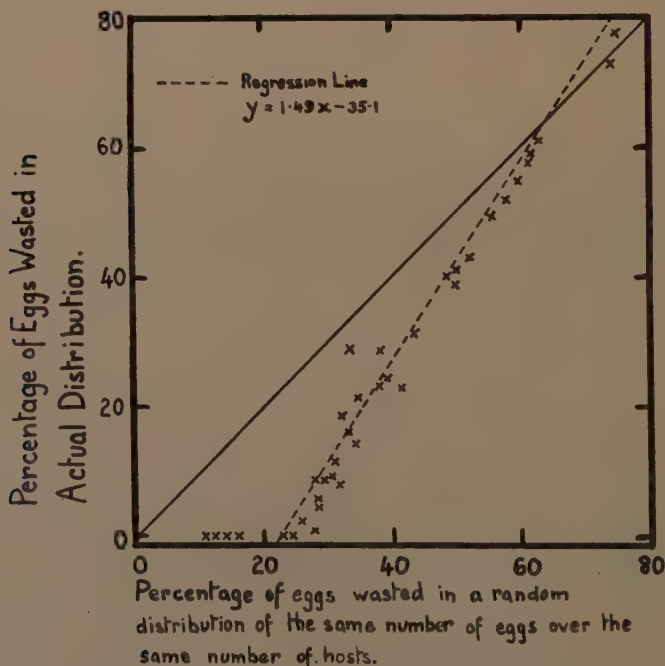


Fig. 2.—Comparison of observed percentage of *Spalangia* eggs wasted due to superparasitism and that expected if eggs had been distributed at random.

Solid line—that on which all points would have fallen had distribution been at random.

The power of discriminating between parasitised and unparasitised hosts will be investigated more fully below, and it may be as well here to discuss further the breakdown of the restraint of the female when she oviposits in hosts which she senses to be parasitised.

For each of the experiments carried out the percentage of eggs used in superparasitism was calculated, for these represent a waste of eggs from the point of view of efficient destruction of the host, and a loss of reproductive capacity of the parasite. The figures thus obtained were compared with the waste that would have occurred with a random distribution of the same number of eggs over the same number of hosts in each experiment, and they are plotted in fig. 2. Obviously, if *Spalangia* females were ovipositing at random, all observed points would be along the solid line. The actual waste of eggs is, however, always (except in one case) less than the figure given by this line, indicating the exercise of discrimination and restraint by the ovipositing female encountering a host that is already parasitised.

The regression line of the observed points has a formula $Y = 1.49x - 35.1$ which cuts the abscissa at a point $x = 23.6$, indicating that restraint only breaks down at a point where, if distribution of eggs were purely at random, 23.6 per cent. of them would be wasted. This would occur with a parasitism of about 60 per cent. (see Thompson, 1924). However, there is no reason to suppose that the observed points lie on a straight line, and restraint probably breaks somewhere near this point. This is supported by the figures in Table I. With increasing P/H ratio, superparasitism first occurs when there is a final parasitism of 58 per cent. (P/H ratio 2/25) followed by that of 62 per cent. (P/H ratio 3/25), 70 per cent. (P/H ratio 4/25), 76 per cent. (P/H ratio 3/25) and 77 per cent. (P/H ratio 2/10). However, in this range of parasitism there are also experiment totals where no superparasitism occurs, i.e., a final parasitism of 67 per cent. (P/H ratio 1/10) and 70 per cent. (P/H ratio 1/10). Thus, in these experiments restraint appears to break down when parasitism reaches a figure of about 60 per cent. It is seen from Table I that with increasing degree of total parasitism at the end of the experiments, the actual distribution of eggs approaches more nearly that expected from a random distribution.

This particular quantitative relationship no doubt only applies to the particular set of conditions under which these experiments were carried out, and any change might alter the point at which restraint breaks down. In particular, the introduction of a "search factor", where hosts were made difficult to find, might well reduce the restraint shown by the female.

There is, therefore, the situation where an ovipositing parasite can refrain from superparasitising a host until about 60 per cent. of the hosts available have been singly parasitised. From direct observation of the ovipositing parasites it is evident that any discriminatory sense is only effective when the parasite is actually in contact with the host, and that these contacts with hosts are made at random and are not directed towards only unparasitised hosts. Though these contacts are at random, the actual ovipositions are not, and it is obvious that if a parasite contacts an unsuitable host it refrains from ovipositing and moves off to another. However, when such unsuitable contacts are too frequent the parasite's restraint breaks down and oviposition occurs. It is of interest to endeavour to evaluate this restraint in terms of the number of unsuccessful contacts that can be made before it breaks down.

It is reasonable to assume from a consideration of all the experiments that the urge to oviposit is largely governed by pressure of mature eggs in the oviduct. It follows that once an egg has been laid restraint is at a maximum and will only break down after a further lapse of time, or, when unsuitable hosts are examined, after a further number of them have been contacted. From this it is possible to arrive at some idea of the number of unsuitable hosts that can be

rejected before restraint breaks down. The results of the individual egg distribution experiments may be grouped according to the final percentage of the hosts that were attacked and then divided into two groups, those where no super-parasitism has occurred, and those where it has. This is shown in Table III

TABLE III.

Analysis of results summarised in Table I, showing the percentage of experiments in which restraint breaks down at different levels of attack.

	Percentage of attack at end of experiment								
	0-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
25 hosts used									
No. of experiments in which restraint does not break down	—	7	20	12	3	6	5	8	3
No. in which it does break down	—	—	—	—	3	3	3	5	42
Percentage of experiments in which restraint does break down	—	—	—	—	50.0	33.3	37.5	38.5	93.3
10 hosts used									
No. of experiments in which restraint does not break down	—	—	—	3	4	6	8	12	9
No. in which it does break down	—	—	—	—	—	1	7	6	64
Percentage of experiments in which restraint does break down	—	—	—	—	—	14.3	46.7	33.3	87.7
5 hosts used									
No. of experiments in which restraint does not break down	—	—	—	—	—	—	8	—	23
No. in which it does break down	—	—	—	—	1	—	5	—	83
Percentage of experiments in which restraint does break down	—	—	—	—	100.0	—	38.5	—	78.3
Total hosts used									
No. of experiments in which restraint does not break down	—	7	20	15	7	12	21	20	35
No. in which it does break down	—	—	—	—	4	4	15	11	189
Percentage of experiments in which restraint does break down	—	—	—	—	36.4	25.0	41.7	35.5	84.4

where the experiments are divided into groups at 10 per cent. intervals from 0 to 100 per cent. attack. "Attack" rather than "parasitism" is used here since it has been shown (Simmonds, 1954) that those hosts that are "stung only" are sensed by the ovipositing parasite as unsuitable, just as if they were actually parasitised. Finally, the percentage of the experiments in which restraint breaks down is determined for each group. These percentages give an

idea of the degree of breaking down of restraint that occurs at various levels of attack and it is noteworthy that even at 100 per cent. attack, restraint does not break down, and thus no superparasitism occurs in 15.6 per cent. of the experiments.

It is possible now to calculate the probability of the occurrence of superparasitism at various levels of attack, assuming that the parasite is capable of restraining herself from oviposition in 1, 2, 3, 4, etc., unsuitable hosts successively encountered. Supposing 10 of a hundred hosts are already parasitised and the ovipositing parasite is about to lay another egg. The chances that, searching at random, she encounters a parasitised egg are $\frac{1}{10}$. Supposing she now exercises restraint and does not oviposit, she will move off and the chances that the second egg she encounters is parasitised are again $\frac{1}{10}$. Thus the chances of two unsuitable hosts being encountered in succession are $\frac{1}{10} \cdot \frac{1}{10} = \frac{1}{100}$, a 1 per cent. probability. This means that if restraint breaks down at this second encounter, superparasitism will occur in 1 per cent. of such cases, in the remaining 99 per cent. two successive unsuitable encounters will not occur when parasitism is 10 per cent.

If restraint only breaks down at the third unsuccessful encounter, superparasitism will occur in $\frac{1}{10} \cdot \frac{1}{10} \cdot \frac{1}{10} = \frac{1}{1000}$ or 0.1 per cent. of the cases. At the 20 per cent. level of parasitism the chances for two successive unsuitable encounters are $\frac{2}{10} \cdot \frac{2}{10}$ or 4 per cent., for 3 such encounters $\frac{2}{10} \cdot \frac{2}{10} \cdot \frac{2}{10} = 0.8$ per cent.; similarly, for higher levels of parasitism and 4, 5, 6, etc., successive encounters.

Table IV has been drawn up from these calculations, giving the calculated percentage of cases where superparasitism will occur at various levels of parasitism and with varying degrees of restraint. A comparison between these

TABLE IV.

Calculated percentages of cases where superparasitism will occur when the ovipositing parasite is confronted with hosts which are already parasitised to a varying extent, and when the parasite is able to refrain from ovipositing in a number of already parasitised hosts that are encountered in succession.

Level of attack (%)	Probability of superparasitism as a percentage if restraint breaks down at					
	2nd	3rd	4th	5th	6th	7th
	successive encounter with an already parasitised host					
0 ..	—	—	—	—	—	—
10 ..	1	.1	.01	.001	.0001	.00001
20 ..	4	.8	.16	.032	.0064	.00128
30 ..	9	2.7	.81	.243	.0729	.02187
40 ..	16	6.4	2.56	1.024	.4096	.16384
50 ..	25	12.5	6.25	3.125	1.5625	.78125
60 ..	36	21.6	12.96	7.776	4.6656	2.79936
70 ..	49	34.3	24.01	16.807	11.7649	8.23543
80 ..	64	51.2	40.96	32.768	26.2144	20.97152
90 ..	81	72.9	65.61	59.049	53.1441	47.82969

calculated figures and those obtained from the experiments and given in the last line of Table III, is shown in fig. 3. Although the observed points do not all lie on any one of the calculated curves, the 61 to 70 per cent., 71 to 80 per cent. and 91 to 100 per cent. points lie on the curve representing breakdown of restraint at the third unsuccessful contact.

It is obvious that this figure is only an average of a very variable value, which differs with different females and fluctuates with their physiological state, in particular with the egg pressure within the oviducts. From fig. 3 it is seen that

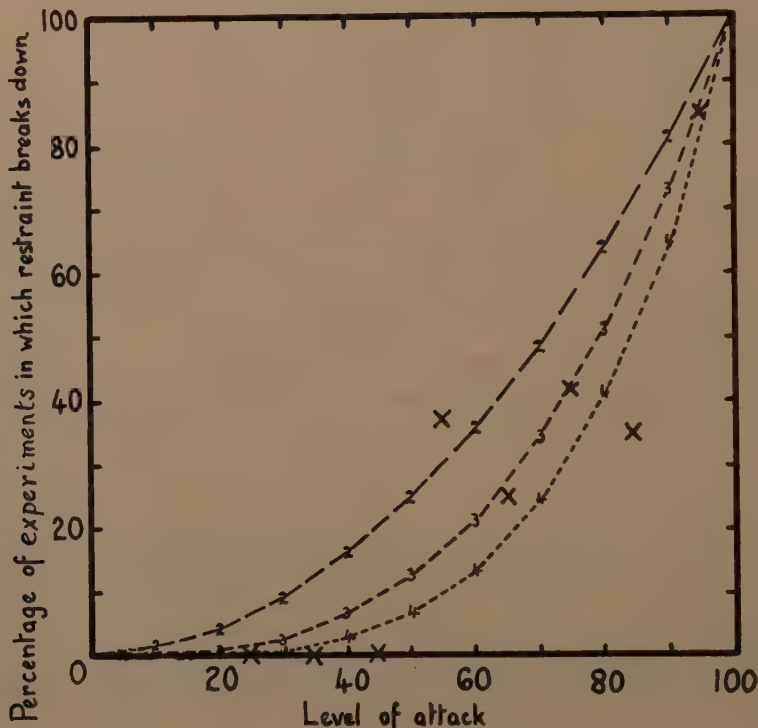


Fig. 3.—Comparison between the observed figures for breakdown of restraint in *Spalangia* (Table III) and those calculated (Table IV).

X—observed figures.

2 - - - 2, 3 - - - 3, 4 - - - 4. Curves if restraint breaks down at 2nd, 3rd, 4th unsuitable contacts, respectively.

at the lower levels of parasitism there is no superparasitism, although the chances of successive unsuitable contacts are not negligible. This is quite understandable if it is the increase in egg pressure that leads to the breakdown of restraint since, at lower degrees of parasitism, the parasite does not often have to exercise restraint, and lack of egg pressure probably enables her to exercise restraint over a number of unsuitable encounters in succession, far better than she could were such encounters more common, as they are at higher levels of parasitism.

Thus, at lower degrees of parasitism no superparasitism occurs, but when parasitism increases and the ovipositing parasite is confronted with a number of already parasitised hosts in succession, she is able to sense that these are unsuitable and can refrain from ovipositing in a number, on an average about three in succession, but after several unsuitable contacts restraint breaks down

and superparasitism occurs. Her urge to lay may, of course, be accentuated by the contact with, and examination of, several puparia.

A further possible result of restraint under conditions where parasitism is high, and one that would tend to help in decreasing superparasitism, would be a reduction in the oviposition rate, a withholding of eggs when suitable hosts were not available. This will be discussed below.

An attempt was made to establish by direct observation a quantitative value for this rejection of successively encountered unsuitable hosts and the results are given below.

Direct Observation.

Spalangia does not lend itself readily to the direct observation of its behaviour with regard to host selection and oviposition since, as has been shown above, each female lays only a few eggs in a day. Consequently, a great deal of time had to be spent to obtain few observations. Several puparia, both parasitised and unparasitised, were placed on a piece of stiff paper and one or two females introduced into the vial which was prepared in the usual way. If no interest was shown in the puparia the females were changed. Once a female began to show some definite interest in a puparium a "running commentary" on the parasite's behaviour was recorded and from this the length of time of examinations of unparasitised and parasitised hosts was obtained, also the time taken for oviposition, etc.

Three time periods were decided upon:—

1. Time for antennal examination—prior to insertion of ovipositor.

TABLE V.

Analysis of the direct observation of a number of examinations of hosts by *Spalangia* and subsequent stinging and oviposition. Variation in duration of different operations with healthy and parasitised puparia.

Unparasitised hosts					
	Examined only	Examined and stung only		Examined, stung and egg laid	
Total no. 	27	35		31	
		Examination	Stinging	Examination	Stinging
Total time taken in minutes 	95	117	789	100	650
Average 	3.5	3.3	22.5	3.2	21.0
Already parasitised hosts					
	Examined only	Examined and stung only		Examined, stung and egg laid	
Total no. 	15	12		10	
		Examination	Stinging	Examination	Stinging
Total time taken in minutes 	26	75	131	40	197
Average 	1.7	6.2	19.2	4.0	19.7

2. Time for stinging—from first insertion of ovipositor to departure from host, this in the case of hosts "stung only".
3. Time for oviposition—from first insertion of ovipositor through egg-laying to departure from host, in those cases where actual oviposition occurred. Periods 2 and 3 include any time taken for feeding at the punctures formed during stinging.

A summary of the data thus obtained is shown in Table V, where the times for examination and stinging or oviposition of both parasitised and unparasitised hosts are given.

There was a wide variation in the times of the examinations and far more detailed work would be necessary to obtain clear-cut differences. However, the figures in Table V indicate that an ovipositing parasite may sense that a host is parasitised and reject it fairly quickly compared with the time spent in examining a healthy host. However, if the parasitised host is not rejected quickly, examination and final acceptance of the host for stinging and oviposition take about the same time, or a little longer, as for an unparasitised host.

There is here direct observation of the existence of a sense which enables the female to discriminate between parasitised and unparasitised hosts. An attempt was made to show directly that a female rejected the first few parasitised hosts that she encountered but would oviposit in one when her restraint eventually broke down. Owing to the few eggs laid per day, however, the figures obtained were unsatisfactory.

Reduction of Oviposition Rate with insufficient available Hosts.

When parasitism is heavy, that is, when P/H ratios are high, the ovipositing *Spalangia* is able to avoid heavy superparasitism in some degree by restricting the number of eggs laid per day. This is another aspect of restraint. Table II shows the average number of eggs laid per female at various P/H ratios, and indicates clearly this limitation of oviposition rate when unparasitised hosts are few or absent, and also shows that when parasites are left with hosts for 48 or 72 hours the eggs laid on the second and third days are fewer than on the first day, indicating the correlation between increase in the ratio of parasitised/unparasitised hosts available and the limitation of oviposition.

In this connection it is interesting to investigate the effect of the previous history of the ovipositing female on the number of eggs laid per day. If a female has available daily a large number of suitable hosts she will lay eggs fairly regularly (see Simmonds, 1953). However, if the number of suitable hosts available has been limited for some time and, through avoidance of superparasitism, the female has reduced her daily egg output, it is possible that an abnormal number of eggs may be available for oviposition when opportunity offers.

In order to investigate this possibility, individual mated females were placed in vials at 75°F. and supplied with a single *Drosophila* puparium daily; these puparia were examined, dissected after 24 hours, and the numbers of eggs laid recorded. After 16 days, 25 puparia were placed with each female daily for 3 days, and then single puparia for a further 8 days, followed by 25 puparia daily for 8 days.

The results given in fig. 4 are very clear. When only single puparia were available the restriction of egg-laying is very marked indeed—only 0.75 eggs per female were laid on the first and second days, the numbers rising slightly as the restraint was exercised day after day. When suddenly excess hosts were available and the necessity for restraint was removed, the number of eggs laid immediately rose to 10.6 per day, dropped to 2.9 on the second day and increased again to 5.7 on the third day. This latter effect is the same as is seen in the egg-pressure

effect in oviposition-rate experiments (see Simmonds, 1953), where initially on the first day of laying a large number of eggs is laid, reducing the egg pressure in the oviducts and leaving only a small number to be laid on the second day, with actual egg production increasing the egg pressure and numbers of eggs laid on the third day. After this period of abundance of hosts, the exercise of restraint comes in again immediately when a single puparium only is supplied, and the second period of abundance of hosts is a repetition of the first.

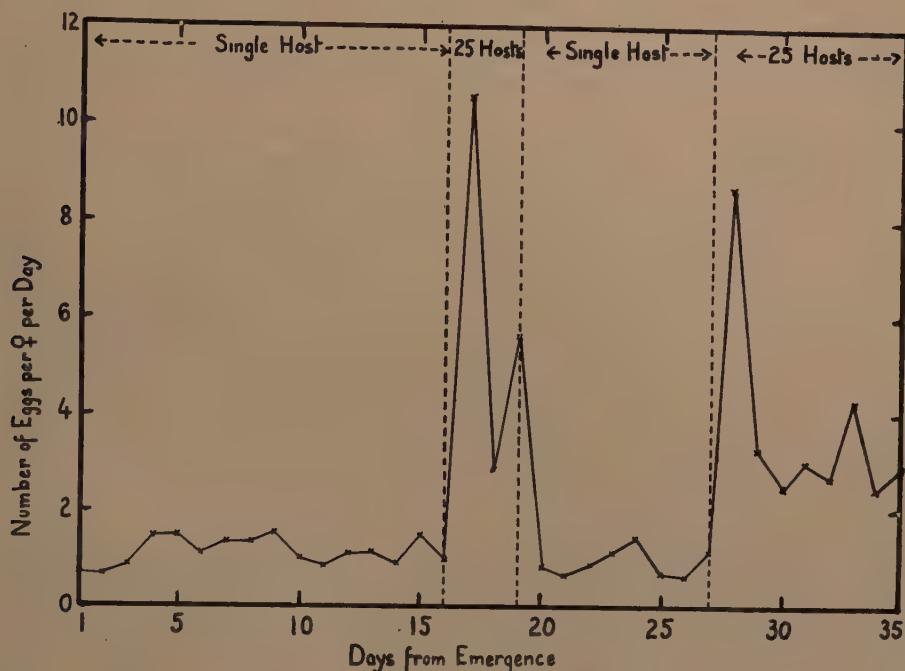


Fig. 4.—Exercise of restraint by *Spalangia*.

This indicates that, as has been seen in the superparasitism experiments, the females have an extremely well developed power of distinguishing already parasitised hosts, and once a host is so distinguished the female restrains herself from laying in it a second time in a considerable number of cases, even though this necessitates maintaining a daily egg output in these experiments below that shown when excess hosts are available. These unlaid eggs are stored in the oviducts, and when abundant hosts are available they are deposited rapidly. Thus the females regulate their oviposition to a certain extent to the number of hosts available.

Discussion.

It was hoped that the results furnished here, together with those obtained on the life-history and biological characteristics of the species, would provide the fundamental data for the theoretical prediction of the course of fluctuation of the *Spalangia* population in the field and the effect it would have on the population of the Frit-fly, *Oscinella frit* (L.).

The further the work progressed the more variable such data were found to be, even under constant conditions. In the case of oviposition—of prime importance in consideration of population increase—there are many factors which affect it,

and introduce so many possible variations in the field as to make it extremely difficult if not impossible to make any basic assumptions concerning the number of eggs that will be laid by a population of *Spalangia* at any given time in the field. It is true that with a population entirely heterogeneous in respect of physiological characteristics, age, etc., these factors could be expressed as an average, but, particularly at the beginning of a season, such a population cannot be treated as an entirely heterogeneous unit.

It is obvious, too, that with the effect of egg pressure, powers of discrimination and restraint, avoidance of superparasitism, and retention of eggs when suitable hosts are not available, fluctuations in the population of host puparia in the field and the degree of parasitism by other species will have a very complex influence on the rate of increase of *Spalangia*.

Several attempts were made, using the data obtained here, to gain an estimate of the possible course of fluctuation of the *Spalangia* population in the field with and without the complicating factors introduced by the presence of other species. However, it soon became evident that such calculations were valueless. Apart from the extremely lengthy calculations involved when an attempt was made to bring into final population figures, the effects of such characters as the variation of developmental time and percentage of larvae entering diapause with the ageing of the parent female, there was the completely unpredictable factor of weather. This factor would act not only in a general way, slowing down development when cold periods occurred, but would also affect the activity of parasites and host, and hence the final populations, by, for instance, periods of sunshine, long or short periods of rain, frost, etc. These are not only unpredictable, with the consequent uncertainty of the conditions under which the populations are going to fluctuate, but also the exact effect which these various facets of the meteorological factor have on the activity and development of the various species is unknown. Hence this part of the work, in attempting to furnish data for the calculation of the fluctuation of field populations, only indicated how impossible this was, and made it clear that any predictions of populations must be entirely empirical, and deduced from the results obtained in the field over a number of years. Further, the general prediction of results is dependent on the meteorological conditions that will prevail.

Summary.

It is known that the females of some species of parasites can distinguish hosts that have already been parasitised and refrain from ovipositing in them. A study was made of the extent to which *Spalangia drosophilae* Ashm. avoids superparasitism of the puparia of *Drosophila melanogaster* Mg. by means of these two steps, which are termed discrimination and restraint, respectively.

Host puparia 0-24 hours old were stuck on paper, with water, equidistant $\frac{1}{4}$ in. from each other and placed in $4\frac{1}{2}$ in. \times 1 in. glass vials into which females of *Spalangia* were introduced for different periods. A series of experiments was set up, in which 25, 10 and 5 puparia were exposed to attack by 1 unmated or 1, 2 and 5 mated parasites for 24, 48 and 72 hours. In this way a wide range was obtained of the parasite-host (P/H) ratio, computed as the ratio of the number of female parasites, multiplied by the number of 24-hour periods for which they were used, to the number of host puparia exposed. Each treatment was replicated ten times, thus entailing a total of 360 experiments. The sequence of events associated with oviposition consisted of examination of the puparium by the females, stinging, followed sometimes by feeding on the fluid that exuded, and finally, but not invariably, oviposition. At the end of the experiment each puparium was examined and the number of eggs present, or the occurrence of stinging only, was recorded. The chance of a puparium being attacked was

unaffected by its position on the paper and there was no significant difference between the total number of eggs that virgin and mated females laid under the same conditions.

The results were assessed by comparing the observed distribution of parasite eggs amongst host puparia with the probable random distribution calculated from a formula that is given. The divergence between these distributions was greatest at the lower P/H values, and very little superparasitism occurred unless these exceeded 3/25, at which point total parasitism reached about 60–70 per cent. As the P/H value increased, so did the total parasitism and the degree of superparasitism, and the deviation of the observed from the random distribution of eggs diminished, although even amongst experiments in which parasitism reached 91–100 per cent., superparasitism was still avoided in 15.6 per cent. of them.

The degree to which females of *Spalangia* can restrain themselves from ovipositing in hosts that have been parasitised was estimated by plotting the percentage of experiments in which restraint was observed to break down, against the level of attack, and comparing the distribution of the points so obtained with the curves that would relate these two functions if the power of restraint was to break down when the female was confronted with 2, 3 or 4 successive puparia that had already been attacked. It is concluded that the assumption that restraint breaks down at about the third successive unsuitable encounter gives the best fit with the observed data.

Contributory evidence that females of *Spalangia* can distinguish parasitised hosts was obtained by direct observation of their behaviour, which indicated that, on the average, females took about $3\frac{1}{2}$ minutes to examine an unparasitised host before deciding whether to attack or not, but, in the case of hosts already parasitised, either rejected them in half that time, or only accepted them after unduly prolonged examination.

When individual mated females were supplied daily for 16 days with a single puparium, then for 3 days with 25 puparia, then again for 8 days with a single puparium and finally for 8 days with 25 puparia, the number of eggs laid daily was restricted to less than two when only a single host was available, but rose to about 9–11 on the first day an excess of hosts was provided and then fell to a normal output. The females thus adapt their egg-laying to some extent to the number of hosts available.

It was hoped that this elucidation of the combination of perfect discrimination but imperfect restraint exhibited by *Spalangia* when ovipositing, together with the data previously obtained on its biology, would make it possible to predict the fluctuations of a population of *Spalangia* in the field and its effect on the natural host, *Oscinella frit* (L.), but the factors involved, and their interactions, are too complex, particularly when weather effects are considered, and it is concluded that any predictions of population must be deduced empirically from field observations over a number of years.

References.

- LLOYD, D. C. (1938). A study of some factors governing the choice of hosts and distribution of progeny by the Chalcid *Ooencyrtus kuvanae* Howard.—Phil. Trans., (B) **229**, pp. 275–322.
- LLOYD, D. C. (1940). Host selection by Hymenopterous parasites of the moth, *Plutella maculipennis* Curtis.—Proc. roy. Soc., (B) **128**, pp. 451–484.
- SALT, G. (1932). Superparasitism by *Collyria calcitrator*, Grav.—Bull. ent. Res., **23**, pp. 211–216.

- SALT, G. (1934). Experimental studies in insect parasitism. I. Introduction and technique. II. Superparasitism.—Proc. roy. Soc., (B) **114**, pp. 450–476.
- SALT, G. (1935). Experimental studies in insect parasitism. III. Host selection.—Proc. roy. Soc., (B) **117**, pp. 413–435.
- SALT, G. (1936). Experimental studies in insect parasitism. IV. The effect of superparasitism on populations of *Trichogramma evanescens*.—J. exp. Biol., **13**, pp. 363–375.
- SALT, G. (1937). Experimental studies in insect parasitism. V. The sense used by *Trichogramma* to distinguish between parasitised and unparasitised hosts.—Proc. roy. Soc., (B) **122**, pp. 57–75.
- SIMMONDS, F. J. (1943). The occurrence of superparasitism in *Nemeritis canescens* Grav.—Rev. canad. Biol., **2**, pp. 15–58.
- SIMMONDS, F. J. (1948). The influence of maternal physiology on the incidence of diapause.—Phil. Trans., (B) **233**, pp. 385–414.
- SIMMONDS, F. J. (1952). Parasites of the Frit-fly, *Oscinella frit* (L.), in eastern North America.—Bull. ent. Res., **43**, pp. 503–542.
- SIMMONDS, F. J. (1953). Observations on the biology and mass-breeding of *Spalangia drosophilae* Ashm. (Hymenoptera, Spalangiidae), a parasite of the Frit-fly, *Oscinella frit* (L.).—Bull. ent. Res., **44**, pp. 773–778.
- SIMMONDS, F. J. (1954). Host finding and selection by *Spalangia drosophilae* Ashm.—Bull. ent. Res., **45**, pp. 527–537.
- SMITH, H. S. (1916). An attempt to redefine the host relationships exhibited by entomophagous insects.—J. econ. Ent., **9**, pp. 477–486.
- THOMPSON, W. R. (1924). La théorie mathématique de l'action des parasites entomophages et le facteur du hazard.—Ann. Fac. Sci. Marseille, **2**, pp. 69–89.
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THE BIOLOGY AND CONTROL OF THE SUGAR-CANE CHAFER BEETLES IN TANGANYIKA.

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The first record of a Melolonthid (cockchafer) larva as a pest of sugar-cane in Tanganyika was in April 1941, when about 25 acres on the Arusha Chini (Moshi) estate of the Tanganyika Planting Company were found to be infested. Subsequently, the main swarming period of the adult beetle has been observed from the beginning of October to late November, and a minor period at the onset of the long rains in March. The identity of the pest was established in 1943 as *Cochliotis melolonthoides* (Gerst.), a native species fairly closely allied to the European cockchafer, *Melolontha*. Several other associated species of minor importance have since been identified. Field and laboratory studies have also been made by W. V. Harris, and his recommendations have enabled a certain measure of check to be kept on the intensity and spread of the damage. The writer succeeded Mr. Harris at Morogoro, and after nearly two years' study of this problem wishes to acknowledge the numerous and valuable data which have been freely drawn upon in preparing the present paper, which is an attempt to summarise the facts known about the cane beetles and the suggestions which have been made for their control. The present recommendations are made in the light of over ten years' study of methods of control of the sugar-cane beetle, *Clemora smithi* (Arr.), in Mauritius and of two seasons' field observations on *Cochliotis melolonthoides* on the above-mentioned infested estate in Tanganyika. The method of chemical control by BHC-dust application in the furrow has since been tested over five years and whilst it has been shown to be essential to protect the virgin canes and to a certain extent the first ratoon, the problem of protecting the second and subsequent ratoons remains a matter for future investigation.

Sugar-cane in various stages of development, both as plant cane and ratoons, begins to show serious signs of root infestation each year in July, and by September or October a seriously infested field will show patches of stunted plants with curled and yellowed leaves; the patches tend to follow the main irrigation furrows. The stools of cane can be lifted easily from the soil, their roots having been severed by the feeding of the larvae. In young plantations, the young shoots and roots are eaten and the larvae then hollow out the setts. In this way, fields which gave 45 to 80 tons per acre in virgin fields and 30 tons in ratoon cane may be reduced to single-figure yields. The infestation spreads but slowly and takes several years to attain its zenith in one field. The environmental resistance to the insect is then slowly built up in the form of insect parasites and predators, fungal and bacterial diseases and these, aided by vigorous cultural measures enable the land to be cultivated profitably once more until the beetle again builds up a population of damaging intensity. The present position is that several hundred acres are gradually being won back to cane cultivation with the beetle advancing slowly but steadily over the rest of the estate. Success in the battle depends largely on the pursuit of a vigorous policy of attack, based on a study of the ecology of the insect.

THE SUGAR-CANE BEETLES.

It is important at the outset that the identity of the species present in cane fields should be known. Although the economic issue is a straight fight between

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the cane plant and its chief enemy *Cochliotis*, there are at least five common species of Melolonthid or allied beetles present, of which one, *Anomala exitialis* Pér., is sufficiently abundant to interfere with the field records if not carefully separated.

List of Species present in the Field at Arusha Chini
(in order of relative importance)

- Cochliotis melolonthoides* (Gerst.) (MELOLONTHINAE)
Anomala exitialis Pér. (RUTELINAE)
Heteronychus tenuestriatus Fairm. (*wilmsi* Kolbe) (DYNASTINAE)
Anomala tendinosa Gerst. (RUTELINAE)
Entyposis impressa Kolbe (MELOLONTHINAE)
Adoretus versutus Har. (RUTELINAE).

***Cochliotis melolonthoides* (Red Cane Beetle).**

ADULT.

This is the largest of the above species and is a typical cockchafer beetle, nearly 1 inch in length (2.0-2.5 cm.) almost cylindrical in form, chestnut brown in colour, with a light yellowish pubescence. The pygidium is not covered by the elytra, and is nearly heart shaped, slightly swollen and coarsely punctate. The original description of the species by Gerstaecker (1867) is given below in translation:

“In size and general facies similar to *Melolontha hippocastani* F.

Head coarsely punctate, each puncture bearing a scale-like hair.

Clypeus twice as long as *frons*, rounded laterally, margins upturned, strongly furrowed at the fronto-clypeal suture which is curved.

Antennal club, light rusty brown, as long as the other 6 segments together and prothorax with slightly bimarginate base, sides of anterior half almost parallel, then tapering distinctly posteriorly, the side margins crenulate and shortly ciliated; surface of prothorax slightly indented in front of the scutellum, punctation sparse on disc, stronger towards edges, each puncture with a small rounded snow-white scaly hair.

Scutellum faintly furrowed, apex smooth.

Elytra more than double the length of the prothorax, a little broader behind the shoulders, slightly truncate at the apex, their surface with 3 indistinct ribs, thickly and evenly punctate and clothed in scales. *Pygidium* squat and heart shaped, slightly swollen, transversely rugose and with scales except on the smooth apex. Thorax and legs with yellowish hairs—the sides of the prothorax and abdomen thickly covered with white scales and bearing longer setae in addition.

One specimen from Uru (November 1862).”

LARVA.

The mature third-stage larva of *Cochliotis* is twice as large as that of *Anomala*, but the first- and second-stage larvae are easily confused with the second and third stages of the other species, and can only be separated in the field by the use of a powerful hand lens. The larva is creamy white in colour, the gut contents showing bluish through the skin in the swollen posterior segments. When fully fed, the development of fat-body and elimination of these gut

contents causes the larva to become yellowish with a waxy, almost translucent appearance. The head is brown, 7.0–7.8 mm. in width, with strong black-tipped mandibles, and the cranial setal pattern is distinguishable from that of *Anomala*, notably by the presence of a fringe of about ten hairs on the anterior frontal margin (fig. 1). The sides of the prothorax are distinctly though lightly sclerotised and the claw in the third pair of legs is reduced to a vestige at the tip of the rather swollen tibio-tarsus. This character serves to distinguish the MELOLONTININAE from the RUTELINAE, in which the three pairs of claws are equally developed, long and slender. The ventral surface of the last abdominal segment shows the highly characteristic spine pattern, the raster. The distinction between *Cochliotis* and *Anomala* is shown in fig. 2, the row of 13 or more pairs of short spines being close and interlocking in *Cochliotis* but widely separate and posteriorly divergent in *Anomala*. There are no spine rows on the raster in either *Adoretus* or *Heteronychus*.

Salient characters which may be used for distinguishing the second-stage larva of *Cochliotis* from the mature larvae of the two commonest species of *Anomala* and *Heteronychus* are shown in Table I.

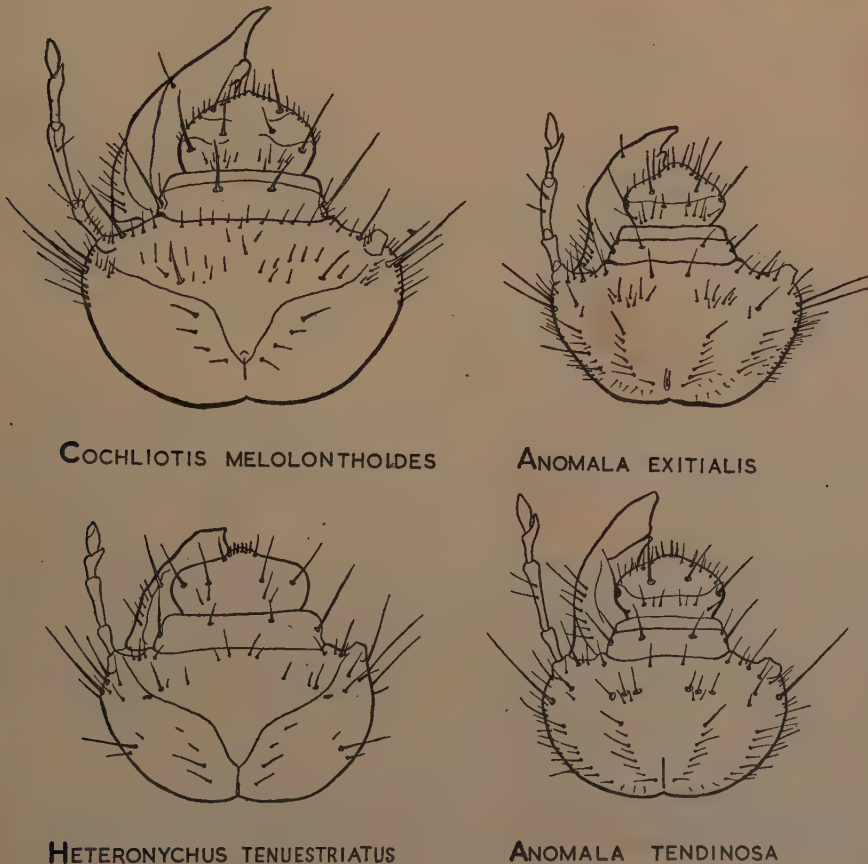


Fig. 1.—Heads of third-stage larvae.



COCHLIOTIS MELOLONTHOIDES



ANOMALA EXITIALIS



HETERONYCHUS TENUESTRIATUS



ANOMALA TENDINOSA

Fig. 2.—Rasters of third-stage larvae.

C. melolonthoides is known from Kilimanjaro, Makindu, Voi and Turiani; the latter record was made by A. H. Ritchie in 1923. It is thus an indigenous insect which has developed pest status in monocultural conditions.

TABLE I.

Characters of the 3 common Melolonthid larvae which may be confused in field surveys.

<i>Cochliotis melolonthoides</i> (second instar)	<i>Anomala exitialis</i> (third instar)	<i>Heteronychus tenuistriatus</i> (third instar)
Head not usually sunk in thorax. Width 4.6 mm.	Head appears enveloped in first thoracic segment when fully grown. Width 4.9 mm.	Head well enveloped especially laterally. Width 4.7 mm.
Head yellowish, mandibles long and black at tips	Head somewhat lighter yellow, mandibles not so conspicuous	Head brown, shortened anteriorly. Mandibles completely black
Legs stout, tip of third (hind) legs swollen and claw reduced	Legs stout, all claws dark, long and of equal size	Legs more delicate, claws equal
Body not swollen posteriorly. Cannot walk uncurved on belly when placed on flat surface	Body as <i>Cochliotis</i> , but walks readily with curve quite flattened out	Body slightly enlarged posteriorly and can walk uncurved. Gut contents (humic) show bluish through skin after 3rd abd. segment

Anomala exitialis (Larger Yellow Cane Beetle).

This species, which has recently appeared also in the Tanga area as a pest, in the adult stage, on cassava foliage, is very distinct from the adult *Cochliotis*. The beetle is somewhat smaller (1.5–2 cm.), oval, flattened and glabrous, of a variable light brown colour, with flattened legs bearing long stout curved claws, typical of the Ruteline sub-family.

The larva is very similar in structure to that of *Cochliotis*, the maturing third-stage larva being practically indistinguishable in field surveys from the 2nd stage of the larger species. The characters already described are sufficient for rapid identification with a hand lens, although in the very young stages they may be insufficiently developed for positive diagnosis, without laboratory examination.

There appears to be no separation of the habitat of *Cochliotis* and *Anomala* and they have been found together in all parts of Arusha Chini.

Heteronychus tenuestriatus (wilmsi) (Black Cane Beetle).

Related to the coconut beetles (*Oryctes* spp.), this genus is found in many parts of Africa, where the chief damage is to young shoots and cane setts by the gnawing action of the adult beetle. The larvae feed principally on humic matter, although they will take roots if present in great concentrations. *H. tenuestriatus* was reported in mid-November 1946 to be causing local damage to young or ratoon cane shoots. The beetle is a squat shining black insect (Black Hardback) somewhat smaller than *Anomala exitialis*. The full-grown larva is similar to that of *Anomala*, although slightly smaller, but there is no double row of spines on the raster, which is composed solely of diffused short setae. The head is smaller in proportion, darker brown in colour, becoming almost black anteriorly, and with shorter antennae. The relative lengths of the antennal segments are shown in fig. 2. This species has not recently caused confusion in larval surveys owing to its restricted occurrence, but it will be a potential danger if a close watch is not kept on its annual progress.

Adoretus versutus (Rose Beetle).

Of world-wide occurrence as the rose beetles, this genus consists of small (1 cm.) unicoloured dull brown, oblong flattened beetles with flattened legs and stout claws similar to those of *Anomala*. The adult beetle of *A. versutus* flies at dusk and is found on the flowers of the common canefield weeds.

The larva is a small creamy white grub with a light brown head and equal claws, the spine rows of the raster being replaced as in *Heteronychus* by evenly distributed setae. The species is unlikely to become anything more than a nuisance in rose gardens.

Entyopsis impressa.

A small Melolonthine similar in facies to *Cochliotis*. This species swarmed at various parts of Arusha Chini in 1937–38, when it interfered with work at the factory. Since this time it has appeared from time to time in small numbers. The larvae are occasionally met in local concentrations, particularly in old weedy grass patches.

Other Species.

A number of adults and larvae have been noted during surveys, but the identity of *Anomala tendinosa* (figs. 1 & 2) alone has been determined. It is not unlikely that as many as ten or more species of the common African genera *Schizonycha*, *Entyopsis* and *Anomala* are involved in the chafer complex at Arusha Chini.

Nature of Habitat.

Since the sugar-cane is not resistant to drought, the sugar estate at Arusha Chini has been developed by irrigating a piece of dry bushland on grey-black alluvial soils, derived from volcanic rocks, in the flood plain of the Pangani river to the south-east of Moshi. Natural rainfall is in the vicinity of 20 inches (average 18.3 in. over 10 years) but the water table has been raised to such an extent that the whole estate has a luxuriant appearance comparable with that of some Javan or Puerto Rican sugar estates. The soils are of a good fine tilth and moisture conditions beneath the cane stools are very favourable to white-grub survival.

Fields are ploughed to eight inches and are harrowed before planting the three-eyed cuttings end to end in furrows eight inches in depth. The variety grown is almost entirely P.O.J. 2878 (the "wonder cane" of Java), although C.O. 421 is now showing some promise. Irrigation is provided by furrows every fifty feet or so and is given every 10 to 14 days during the dry season (May–October and December–March). No compost or pen manure has hitherto been given, but sulphate of ammonia, molasses and filter-press cake are employed. Planting is done in almost every month except July and the canes mature in about eighteen months. Plant canes will thus be exposed to two seasons of maximum grub attack if planted between December and June, and will make their best start on infested land if planted in August–October, when actively feeding third-stage grubs are at their minimum.

On maturing, the fields are fired to burn off the trash, and after cutting, the stools are "ratooned", i.e., divided with the hoe. This process ensures vigorous regrowth and avoids excessive ridging with age, which would interfere with irrigation. It does not, as far as can be seen, have any significant effect on infestation. Ratooning has been practised for as long as ten years in the same field, with economic results on non-infested land, yields being in the vicinity of 45 to 50 tons per acre in virgin stands and 20 to 30 tons in ratoons. Infestation by *Cochliotis* reduces the virgin yield commonly to 15 to 20 tons and eliminates the ratoon crop after one or two years.

Biology of *Cochliotis*.

As far as can be judged by noting the season of maximum damage (July–August), from a study of past and present records, and from a knowledge of similar species in other sugar-cane countries, *Cochliotis* has a life-cycle of one year. The main cycle is as follows:—

Adult beetles have a main swarming season from early October, with the onset of the first showers, to the end of November. A subsidiary swarming, taking place at the beginning of the rains (March), is thought to be due to persistence of larvae and pupae at the latest extreme of normal biological variation.

There must be a considerable preovipositional period of maturation, for eggs and young larvae are particularly abundant in the soil from December onwards, and only decrease slowly in numbers as the season advances. Surveys showed as many as 80 per cent. of first and second stages in April 1944 (Harris). The egg period is about fifteen days, as is usual in the Melolonthids.

Third-stage larvae in their intensive feeding period are in maximum abundance from June to August, after which time they acquire a yellowish white waxy appearance, become sluggish, and finally may descend to depths of 18" to 3 feet, where they make a cell and pupate. In order to obtain a picture of the spatial distribution of white grubs in relation to the cane plant, it is convenient to carry out field dissections of cane stools. The method employed is to make a trench 3-ft. deep along a cane row, at a distance of 3 ft. from the centres of the

plants. The wall of the trench is then carefully picked away by means of an awl or other pointed tool. The position of each insect found is then mapped on a system illustrating both horizontal and vertical distribution. The result of a typical excavation of a badly affected ratoon stool, made in August 1946, is given in fig. 3, and demonstrates the high degree of protection from parasites,

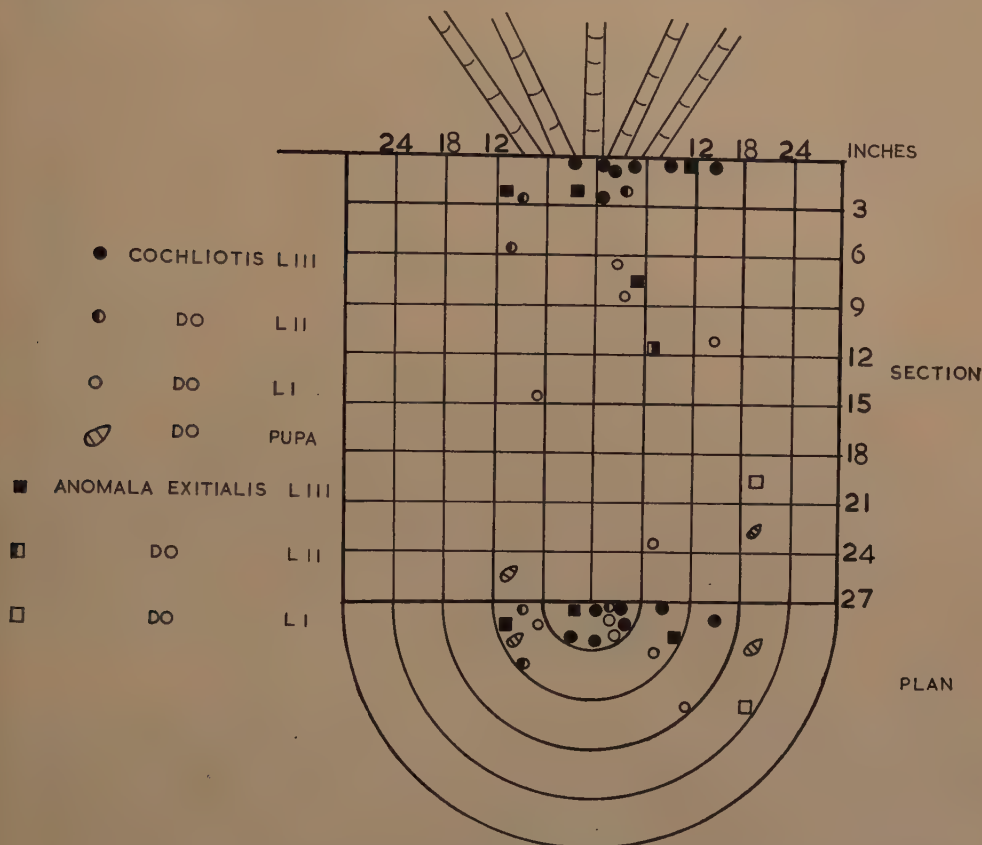


Fig. 3.—Diagram showing horizontal and vertical distribution of chafer larvae around a ratoon cane stool.

from desiccation and from cultural measures, afforded to a large percentage of the larvae. As the large larvae of *Cochliotus* approach maturity they tend to seek, more and more, the woody portions of the cane plant and are frequently found in burrows made in the underground stems, or in the cane setts. They are, however, capable of living in the dry friable soil constituting the first three or four inches of the canefield surface. It is common to find the younger stages and particularly the early third-stage larvae of *Anomala* spp. in the moist compacted lower layers below 12 inches in depth. The pupae are generally found in cells twelve inches or more from the surface, although many have been found *in situ* in the woody tissue of the cane stool. It is to be observed that the pupae of *Cochliotus* cast off the old larval skin, which is pushed to one end of the pupal cell, whereas those of *Anomala* lie within the split larval skin.

After a pupal period of about fourteen weeks, but varying with soil moisture, the adults emerge *en masse* in early October. They fly for a very short period

at dusk, and do not cover any great distance. On October 25th 1946, flight began at 1840 hr. and by 1905 hr. hardly a beetle was to be found. They have never been observed feeding, and cane leaves show few traces of the large number of individuals which must pass amongst them. Observations made in October 1947 suggest that the flight is exclusively devoted to mating; the males are seen fighting for possession of the far less numerous females. No evidence of feeding during the short flight which again took place on the average between 1840 and 1900 hr. was seen, nor was any defoliation of nearby plants noted subsequently. The adult beetles spend the day in the soil, and in one case were lying thickly just below the short turf of a golf course near the estate factory.

A diagram illustrating the life-cycle of the Red Cane Beetle is presented in fig. 4. The subsidiary flight is evidently due to a variable proportion of each

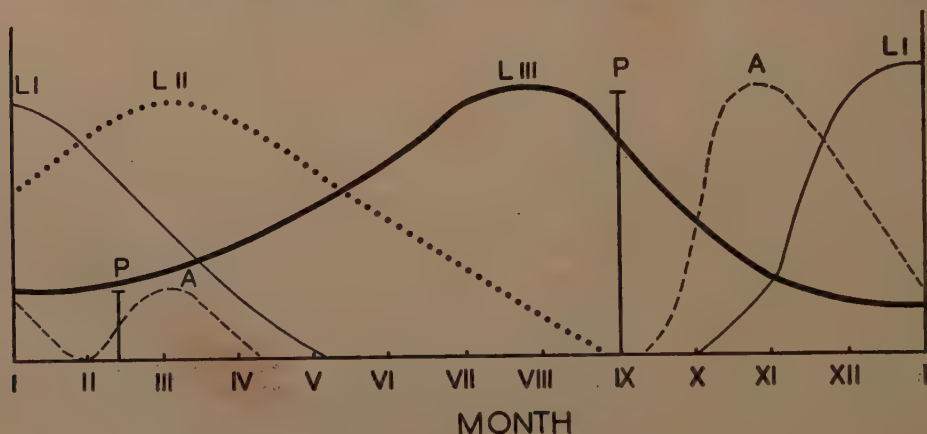


Fig. 4.—Seasonal life-cycle (schematic) of *Cochliotus melolonthoides*.
LI, LII, LIII—larval stages; P—pupa; A—adult.

generation whose larvae are not fully fed by August, and whose late formed pupae do not emerge until the hot dry period of December and January is relieved by the heavy rains of March. The annual seasonal flights may be kept constant by the complex of environmental factors which act selectively upon the mixed populations present in the area. These factors are drought, insect and fungal enemies, and cannibalism by the main generation.

Biology of Allied Beetles.

Anomala exitialis.

Observations made in 1946 and 1947 indicate that the life-cycle is annual and that flight takes place after that of *Cochliotus*. Fully fed, white translucent larvae are found commonly in October, and a number of larvae kept in the laboratory pupated in November, and emerged in mid-December. On a peasant holding (shamba) near Tanga, the adults were reported to be damaging cassava foliage during December. The larval habits of *Anomala* closely resemble those of *Cochliotus* but there is less tendency for the smaller larvae to attack the hard lignified tissues of cane setts, or rhizomes in ratoons.

Heteronychus tenuestriatus.

Adult beetles are found from August with a maximum in November, when they have been observed swarming in the cane fields. In this stage they cause much damage by burrowing into the soil and eating out the eyes and young

shoots of plant or ratoon canes. The larvae feed to a great extent on decaying roots and detritus, but when numerous, are recorded as damaging living roots. They live and pupate within 4 to 6 inches of the soil surface, in contrast to the other species which have been found as deep as 3 ft. in the soil.

Course and Intensity of Infestation at Arusha Chini.

It is of interest and significance to consider the progression of the mass infestation which has occurred on the sugar estate at Arusha Chini. Since *Cochliotis* is an indigenous insect, with a fairly wide distribution in Tanganyika, it would be reasonable to expect that on submitting an area to monoculture, the insect would acquire pest status at a number of different places on the estate, such places finally coalescing. In the event, there appears to have been a steady invasion of the southernmost section, extending since 1940, when the infestation was first noticed, in an adjacent Indian estate, about two miles into the richest part of the estate.

The method of assessment of the population density now employed is to dig out a soil sample 3 ft. \times 2 ft. \times 1 ft. deep embracing a single stool and the portion of interline covered by its root system. This is a laborious proceeding and should be reduced to a minimum. In Mauritius, it was found adequate to dig ten holes per acre, in order to estimate the grub population within 5 per cent. provided the infestation exceeded 10,000 per acre. At this figure the frequency distribution of samples is nearly normal, but at lesser densities it approximates to a Poisson distribution and the mean value obtained in surveys is more variable, with high standard error. However, in practice, the economic limit of damage is around 8,000 to 10,000 larvae per acre, and a larger error in population estimations at the 2,000 to 5,000 level is of little consequence. Larval populations then are expressed as the number of all stages and species per acre. For Arusha Chini, we can regard the following figures as significant:—

Light infestation (no visible sign of damage)	1,000–8,000 per acre
Medium infestation (patches of yellow cane)	8,000–20,000 per acre
Heavy infestation (complete destruction of stools)	20,000–100,000 per acre

The expression of numbers in acre units reflects the discontinuous distribution of the larvae under the cane stools better than does the square yard unit applicable to pasture pests such as the British *Anomala horticola* (L.).

In the course of time, the first invaded fields at Arusha Chini, which originally carried populations of around 100,000 *Cochliotis* larvae per acre, were replanted, after having been abandoned for two years, and gave a reasonable yield in the virgin crop, although patches of infestation were still visible, and infestations of 15,000 larvae per acre were recorded. On the other hand, old ratoon fields, some 1.5 to 2 miles towards the unattacked side are generally doomed to extinction, their root systems being almost completely severed by populations of 5 to 20 larvae per cane stool (20,000–80,000 larvae per acre). Further into the estate, in the still unaffected adjacent fields, patches of grubs are found which will assuredly cause damage in succeeding years. The furthest point of mass invasion, up to 1948, had been the European quarters near the factory four miles from the original infestation, where the golf course in 1947 harboured a population of 5 to 10 larvae per square yard. (In October 1947, the beetles were seen swarming round ornamental trees in this area.) Recent reports (1954) state that the beetle is now universal on the estate.

The story is thus very similar to that found in Mauritius in the case of the imported Melolonthid, *Clemora smithi*, which has swept successively over many sugar estates during the past forty years, leaving behind sporadic infestations which may on occasion reach alarming proportions, as at Belle Vue Harel Estate in 1941. There is nothing in any observations made to date to suggest that the infestation is generally on the decline, nor that areas at present free from the pest will not inevitably be invaded during the next ten or fifteen years. A serious view should be taken of the prospects and every possible means employed to combat the pest.

Sources of Economic Loss.

The nature of the financial losses due to the presence of white grubs on sugar-cane in Tanganyika are fourfold:—

1. Failure of virgin fields or their delay in becoming established, owing to the direct destruction of the seed piece and the young growth. The result of heavy early attack which usually affects cane planted in March to May, the best planting season, is a direct loss of virgin crop and retardation of at least the first ratoon. Such plantings have to face two seasons of maximum attack (June–August) before maturation (October–November).
2. Progressive reduction of yields and untimely elimination of ratoons, on which the prosperity of the estate largely depends.
3. Extra costs involved in such operations as filling in the gaps and extra weedings, fertiliser and water application, consequent upon the delay in formation of a suppressive canopy.
4. The denial of large stretches, often amounting to 15 per cent. of the arable area of the estate, to cane cultivation, for periods of from one to three years.

It would be idle to attempt to estimate the financial losses involved, since they are so frequently counterbalanced, in accounting, by development, price fluctuations and others factors irrelevant to the insect problem. Suffice to say that the entomologist is in a position to advise on measures to minimise these losses.

PROPOSALS FOR CONTROL MEASURES.

Proposals for improving the control of *Cochliotis* and its allies on Arusha Chini estate fall into three main classes, cultural, biological and chemical.

In order to be able to assess the relative value of the many natural factors which normally produce the high mortality of the numerous progeny of insects, it is necessary to make critical and detailed studies under continuously controlled conditions over a number of seasons. Whilst such studies are highly informative, the interaction of physical, biotic and intrinsic mortality factors is so complex that any simplification or codification of control recommendations for the benefit of the planter based on such studies must of necessity presuppose an awareness on his part of the phenological manifestations of both insect and plant biology. In practice it is rarely that a planter, beset with a multiplicity of problems, is able to base his control measures on such observations. Our task would appear to be to place a set of more empirical rules in the hands of the grower, which can be applied readily by rule of thumb.

With this idea in mind it may be said at once that precise knowledge of the incidence and extent of the sequence of mortality factors in MELOLONTHIDAE in general and of *Cochliotis* in particular is almost non-existent. This is largely due to the great practical difficulty of rearing soil insects in significant numbers in conditions of continuous observation, without vitiating one or more of the important environmental factors. It is possible, however, with a sound background of experience in general bionomic study of the group to offer an admittedly

subjective assessment of the trend of mortality over a single generation of the beetle.

TABLE II.

Mortality factors operating against populations of Melolonthids.

Stage	Nature of factor operating in Tanganyika	Estimated percentage of stage eliminated in course of one generation
Adult beetle (preovipositional)	Predators (bats), internal fly parasites	10-20
	Desiccation prior to emergence	0-50
Eggs	Excessive drought or moisture	20-75
	Natural sterility	5-10
First-stage larvae	Predators (Carabid beetle, Asilid larva, etc.)	20-50
	Desiccation prior to finding food	20-30
	Mutual infliction of wounds in high densities	10-20
Second-stage larvae	Predators and wounds as above	10-50
	Parasites, smaller species of <i>Campsomeris</i> (<i>C. felina</i> (Sauss.), <i>C. lachesis</i> (Sauss.))	10-25
Third-stage larvae	Predators and wounds (effects accentuated by frequency of encounter)	25-50
	Parasites; <i>Campsomeris mansueti</i> (Gerst.) (digger wasp); Nematode worm: mites in body folds	20-50 (inclusive of destruction by paralysis only without oviposition)
	Diseases; bacterial invasion of lesions causing discolouration and flaccidness	20-75
	Elimination of supply of suitable food	0-5
Pupae	Predators (Elaterid, Carabid)	20-50
	Desiccation	20-80
	Mechanical obstacles to emergence	10-20

It is often observed that Melolonthid beetle populations in any one unit of area (a field of five acres for example) do not normally undergo violent season to season fluctuations, rather that progress of infestation shows a steady build-up followed by a more rapid fall as the factors of mortality come into operation. The figures for beetle collections made under comparable conditions in a number of typical infested cane fields in Mauritius will serve to illustrate this trend (fig. 5).

A summation of the minimum estimated mortality factors in the Table given above would allow of a four-fold multiplication (assuming a 1:1 sex ratio) which is seldom met in the field in a single season. On the other hand, a high value of one or two factors may be sufficient for complete control of the population, i.e., total real mortality is greater than 98 per cent. in one generation.

Whether the natural destruction of populations takes place by localised quanta of catastrophies or by a relatively steady, if varying, incidence of a sequence of factors, it is obvious that we should beware of excessive theorising on the possible interactions of this complex of factors, which it is our aim to augment to the advantage of the planter.

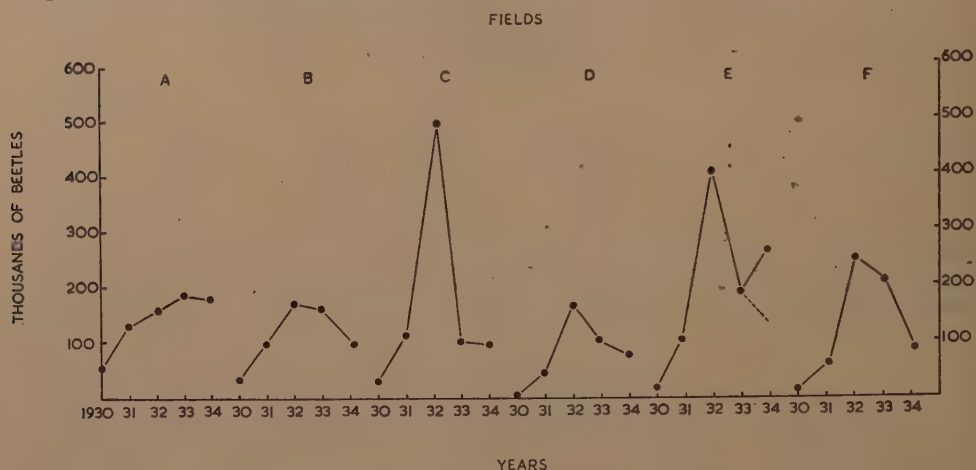


Fig. 5.—Progress of Melolonthid infestation in a number of typical infested cane fields in Mauritius.

Cultural Control.

Under this heading are grouped all the modifications of estate practice which tend to resist or avoid the brunt of the insect attack. It also includes, at its head, the direct and obvious method of control by hand collection.

Hand collection of adults and larvae.

In the case of *Cochliotus*, the hand collection of adults would be a practical impossibility owing to the extremely limited period of crepuscular flight. The principle of the method is, however, so frequently advocated that it is interesting to point out that hand collection of *Clemora smithi* was practised on an island-wide scale in Mauritius for twenty-five years until the present writer was able, in 1934, to demonstrate the complete inefficacy of the method (Jepson, 1936a). Let this be no generalised condemnation of the method which is still in use in Barbados, where it is said to give good results. With certain provisos, it is possible also to condemn special efforts in the destruction of larvae. Whilst it is not intended to discourage the intensification of ploughing, ripping and harrowing operations, the best efforts at larval destruction achieve but a temporary improvement in the midst of an area which is heavily infested. The reason for this is perhaps not difficult to see when it is considered that the planter has to compete with a natural mortality in this stage which may amount to 75 per cent. or more. With a distribution of grubs in the soil, as shown in fig. 3, and with a large population in inaccessible waste ground, in cane roads, along water furrows, and under standing cane, the digging of grubs as a control measure is a process more satisfying to the soul than to the pocket.

Tillage practices as control measures.

It has been shown in Mauritius by the writer and elsewhere, that even the best efforts at interline cultivation by the hand hoe, bullock hoe, or fork, cannot

be carried near enough to the stool to have sufficient direct destructive effect on the larvae. At Arusha Chini, the process of "ratooning" or splitting the cane stools immediately after harvest, destroys but an insignificant fraction of the population, and cannot be regarded as a control measure although it is an essential cultural operation.

In abandoned or replanted areas, the energetic working of the soil may destroy a fair fraction of the resident larval population. Natural enemies are of course destroyed indiscriminately, and the sum total of results is frequently disappointing, evidently because the rate of larval destruction falls below that required to produce a quick reduction in the field population. When it is considered that a residual population of one or two larvae per plant in the previous crop is sufficient to cause serious damage to a new plantation, the efficiency of mechanical destruction must reach a high level if the original infestation were of the usual order of 10 to 20 larvae per plant. In practice, it cannot be relied upon to give more than a temporary and local control, and the practical recommendation is to stir the soil to the limit allowed by prudent local agricultural practice, but not to resort to special hand digging and picking of grubs on a bonus system.

Time of planting.

As stated above, the optimum planting period is from July to October, when the fully fed larvae move to the lower soil levels and pupate. The cane is thus exposed to only one major attack of larvae, *i.e.*, from April to June of the following year, by which time the stool has attained its full development.

As frequently happens, this recommendation embraces the two cool dry months of July and August, which are not popular planting times. It is to be noted that minimal numbers of third-stage larvae are frequently recorded in January and February, but these insects are feeding vigorously and young cane plants suffer severely if the fields are planted during these favoured planting months in badly infested areas.

Rotation of cane crops.

Existing practice at Arusha Chini has been to take annual cuts of cane (ratoons) for 8 to 10 years wherever possible. It need hardly be stressed that such a practice provides optimal breeding conditions for Melolonthids. The extensively woody cane stool protects the larvae from the searching of natural enemies and severely restricts any measure of cultivation or of chemical control.

With the advent of improved mechanical cultivation and of quick-maturing, higher-yielding varieties, it should be practicable to reduce ratoons to about three, and then to clean the ground with a quick-growing crop such as white mustard, or beans, ploughed in as a green manure. Maize and sorghum, alternate hosts of the cane borer, *Busseola fusca* (Fuller), should be avoided on the estate as a whole. The groundnut, cotton, sunflower and beans should thrive under irrigated conditions.

Regulation of irrigation.

It has long been observed at Arusha Chini estate that the larvae of *Cochliotis* are most abundant along the irrigation feeder and waste water furrows. The relatively high water table which is maintained in the fields favours the persistence of infestation as well as the development of saline conditions. If a regrading of the irrigation system were found to be beneficial for the latter problem, a lower water table would no doubt make conditions less favourable for the grubs, and on balance more favourable to the development of the cane.

Varietal resistance.

Amongst cultural measures, the planting of a well-adapted variety is probably the most effective single factor, and although P.O.J. 2878 is known to have a relatively resistant root system, it is not good enough against *Cochliotis*.

Characters associated with resistance are:—

1. Abundant tillering, quick growth and maturation.
2. Volume of root growth.
3. Quick regeneration of roots from numerous dormant root primordia at the base of the shoots, after the primary roots have been severed by the larval feeding.

Importations of three of the most resistant varieties from Mauritius have therefore been made, and the vigorous M. 134/32 and the newer M. 165/38 may well succeed in Africa under irrigated conditions.

The Coimbatore variety Co. 421 has been showing some general promise and its free tillering habit may offer some resistance to the grubs. However, it has been recommended that a wide range of new importations, including some of the more promising varieties from the West Indian Cane Breeding Station be made as soon as more adequate quarantine facilities are again available.

Biological Control.

Under this heading, natural enemies of the Melolonthids will be considered, with some suggestions as to possible future sources of parasite material.

There are two practical aspects of control by natural enemies.

1. *The encouragement of parasites and predators already present.*

Since *Cochliotis melolonthoides* was formerly a rarity, only recorded from wooded mountain slopes, e.g., Kilimanjaro, it is reasonable to regard its present habitat as an ecological island.

During the present study, the following natural enemies were observed:

Hymenoptera (SCOLIIDAE).

Campsomeris (Dielis) mansueta (Gerst.), *C. felina* (Sauss.), *C. lachesis* (Sauss.) and *C. caelebs* (Sichel).

Of these, only the first species is large enough to attack the third-stage larva of *Cochliotis*. The remainder will probably normally attack the smaller Melolonthines (*Anomala* spp.), and at the appropriate season the second-stage larvae of *Cochliotis*.

Coleoptera (ELATERIDAE).

An Elaterid larva of the predacious group was found uncommonly under the cane stools. This larva attacked Melolonthid larvae readily in captivity.

Coleoptera (PASSALIDAE).

The larvae of *Didimus sansibaricus* Har. were found to be feeding on *Cochliotis* and were common locally in infested fields. Their value as a factor of mortality is undoubted but most difficult to assess.

Nematoda.

Out of 500 larvae of *Cochliotis* dissected, two were found to contain a nematode, but this would appear to be of no practical importance.

No Tachinid parasites either of adults or larvae were found, although several thousand beetles were kept with food until they died, and many hundred larvae were dissected and carefully examined.

The main species of Scoliid wasp attacking the third-stage larvae of *Cochliotis* is the black and yellow *Campsomeris mansueta*. A study of the canefield weeds and cultivated crops has shown that none of the common weeds such as "black jack" (*Bidens pilosa*), *Commelina*, *Amaranthus* and *Ageratum*, is visited regularly by the wasps. A recommendation by Harris that cotton should be grown in the rotation on infested ground led to a great increase in *C. mansueta*, and this is even more marked where "Kunde" (*Vigna* sp.) and haricot beans were included with the cotton. The disadvantage of all these plants is that they occupy arable land and that they flower for a short season only. A search was therefore made for a perennial which would be confined to the cane roads and waste ground. Such a plant is well known in Mauritius, Java and the Philippine Islands in the genus *Stachytarpheta*, the blue rat tail, and has been widely propagated in cane fields.

In Tanganyika, the writer first located a light blue species of *Stachytarpheta* on waste ground in the Rufiji flood plain at Utete. This was raised from seed at Morogoro and established at Arusha Chini. Subsequently a darker blue variety, more attractive to *Campsomeris*, was found in a garden at Tanga and this has been widely propagated at Arusha Chini where it is by nature strictly confined to consolidated ground in between cane fields and along water furrows. The plant is easily controlled by cutlassing when it becomes large and bushlike.

Since the presence of large Scoliid populations has never been seen in completely clean-weeded cane fields, positive measures to provide a perennial supply of attractive food plants must always be taken on infested estates.

2. The introduction of parasites from Africa, outside Tanganyika.

From experience in other parts of the world the writer would make the following suggestions:—

- i. *Adapsilia latipennis* (Wlk.) (Diptera, Ortalidae).
- Pezopsis pyrrhaspis* Villen. (Diptera, Tachinidae).

These species are parasites of the adult of *Hypopholis sommeri* Burm. in Natal, but have a wide African distribution, and material could be obtained relatively easily from the Richmond district of Natal, where *Hypopholis* occurs in plantations of black wattle. The beetle is similar in size to *Cochliotis* and the parasites travel well in the pupal stage.

- ii. *Dexiomorpha picta* (Mg.) (Diptera, Tachinidae).

A parasite of larval Melolonthines and especially of *Rhizotrogus carduorum* Erichs. in the Zaers forest area of Morocco (Moutia, 1940), it is thought that this species would be worth trying at Arusha Chini, where irrigation and the proximity of the Pangani river have provided shady habitats suitable for adult Tachinids.

3. The introduction of parasites from outside Africa.

In the course of the search for parasites of *Clemora smithi* the writer examined many Melolonthines which closely resemble *Cochliotis* in size and habit. The following species are suggested as offering sources of parasite material:—

- (i) *Puerto Rico*. The larger Melolonthids, *Cnemerachis portoricensis* (Smyth) and *C. vandinei* (Smyth) (cited as *Lachnosterna* in Jepson, 1936b), were parasitised in the adult stage by the Tachinid, *Cryptomeigenia aurifacies* Walton. This species could easily be bred and transported in the pupal stage to Africa, and is abundant locally in Puerto Rico.

The giant toad, *Bufo marinus*, imported in 1930 into Puerto Rico from Trinidad caused a great decrease in *Cnemerachis* populations in the cane fields. Since this wholly beneficial species was so easily obtainable, it was imported into Tanganyika in 1948, but it has not yet become established.

The orange and black Scoliid, *Campsomeris dorsata* (F.), might be a useful importation to the African continent as it attacks Dynastids of the genus *Ligyrrus* as well as *Cnemarachis* spp. It was bred successfully in Mauritius on *Clemora smithi*, and is well adapted to drier climates. This species might aid in the control of the black hardbacks (DYNASTINAE) such as *Heteronychus* spp. in sugar-cane and maize in South Africa and Australia and *Heteroligus meles* (Billb.) (*claudius* (Klug)) in yams in West Africa.

(ii) *Banka* (Indonesia). The Asian Tachinids, *Urodexia uramyoides* (Townsend) and *Hamaxia incongrua* Wlk., were found attacking the adults of *Lachnosterna* (*Holotrichia*) *bidentata* Burm. in native gardens. *Hamaxia* has a wide distribution in south-east Asia, and might well become adapted to irrigated conditions in Africa (Jepson, 1936a).

(iii) *Java*. It is not felt that there is much to be gained by the importation of Scoliid parasites of MELOLONTHINAE additional to *Campsomeris mansuetor* already present, but the larger Javan species, such as *Campsomeris javana* Lep. and *C. lindenii* Lep., would be easy to collect and ship if a collector were working in this area. Experience has shown that surprising results are often obtained by transferring these species to new environments, and their inclusion in any complete parasite scheme should be seriously considered.

An interesting, exceptionally large species of *Tiphia* was found at Wadjak (E. Java) in 1936 attacking about 1-2 per cent. of the larvae of the Ruteline, *Anomala* (*Euchlora*) *iridis* (F.), in native cassava and maize gardens. With abundant host material of a similar size, this Scoliid might build up useful populations if imported into Africa.

(iv) *Malaya*. A golden brown Scoliid, *Campsomeris prismatica* (Smith), was found commonly in 1935 at Fraser's Hill where it attacked larvae of *Leucopholis* sp., which occurred in large numbers in the turf of the golf course and surrounding grass. It would be a matter of no great difficulty when political conditions permit, to obtain shipments of this wasp, which should attack a larva of the size of *Cochliotus*.

The writer is of the opinion that the study of some of these aspects of biological control should not be neglected. The immediate outlook should be conservative, since the record of control of Melolonthines by parasites or predators is admittedly not striking. Since, however, the cultivation of sugar, cereals and cassava will be extended in E. Africa, the Melolonthine problem is of long-term importance, and chemical control can at present only be successful locally where cultural practices and the ecology of the insect are favourable.

Chemical Control.

The record of the control of Melolonthids by chemical means has in the past been strewn with failures. If we confine our review to pests of agricultural crops, measures have been practically confined to some form of soil treatment for larval control. Emergence of the adult beetles are generally too extensive and capricious for the success of spraying or dusting operations. Only in Queensland has fumigation of the cane stools by injections of carbon bisulphide or of dichlorobenzene emulsions proved economic on a limited area. More recently, the placing of DDT and BHC in soil has been developed so that long persistence is achieved. Reports from Mungomery (1951) now indicate that BHC will soon replace all other forms of treatment. The writer initiated some trials in Mauritius in 1945 with surface applications of 0.65 per cent. dusts of γ BHC to young infested sugar-cane, but the results were quite negative.

In Tanganyika, where planting in furrows is practised, a number of treatments were tested.

In the first instance, BHC (0.65% of γ BHC) was applied directly to established cane plants as soon as infestation was detected. The survey of larvae was done by random diggings, 1 ft. deep, of the area occupied by 1 plant of cane, *i.e.*, 3 ft. \times 2 ft. The average number of larvae of *Cochliotis* found in these surveys was 13.5, or about 90,000 of all stages per acre, a very high density. Subsequent surveys showed no detectable difference in treated or untreated plots and the whole field was badly damaged. The next step was to apply DDT or BHC at planting, in the form of slurries in which the cane setts were rolled. In these trials, 5 per cent. DDT and 0.65 per cent. BHC dusts were used, and once again the larval surveys after six months' growth showed no difference in numbers between treated and control plots. However, in the plots treated with BHC the growth was so striking as to indicate that a degree of protection to the plant was conferred by the chemical. A shoot count in treated and untreated plots gave some difference but it was not significant.

TABLE III.

Effect of BHC treatment of setts on number of shoots six months later.

Treated plots		Control plots	
Plot no.	No. of shoots	Plot no.	No. of shoots
1	745	2	592
3	1163	4	689
5	1402	6	631
7	1585	8	1190

Mean of treated plots (1,227) mean of untreated plots (775), 452 ± 231.6 .

Variety: P.O.J. 2878. Planted: 10th May 1947. Examined: 6th Nov. 1947.

Treatment: Setts soaked in slurry of 0.65% BHC dust.

Although this difference is not significant, when taken together with the general superior growth of the treated plots, it indicated that some protection without marked phytotoxicity was being achieved.

A further replicated block experiment was laid down in November 1947 with the following treatments at planting:—

1. Control, untreated
2. 2.5% γ BHC dust, as slurry
3. DDT/diesel oil/clay emulsion, 1 in 25 (0.2% DDT)
4. 6% γ BHC wettable powder, 1 in 40 (0.15% γ BHC)
5. 2.5% γ BHC dust in furrow, at 8 oz. per 50 ft.

The liquid treatments were applied in oil drums by immersing the cane setts for ten minutes and allowing them to dry in the sun. The BHC dust was applied from a $\frac{1}{2}$ lb. measure by shaking into the furrow. The soil was lightly mixed before planting the setts which consisted of 3-eyed top cuttings. Weekly counts of the number of shoots produced (fig. 6) and observations on the progress of growth were made over the first three months of growth. These counts were supplemented by a final assessment of the size grading of the shoots according

to the height attained at the end of the experiment, which was terminated owing to the absence of the writer from the Territory.

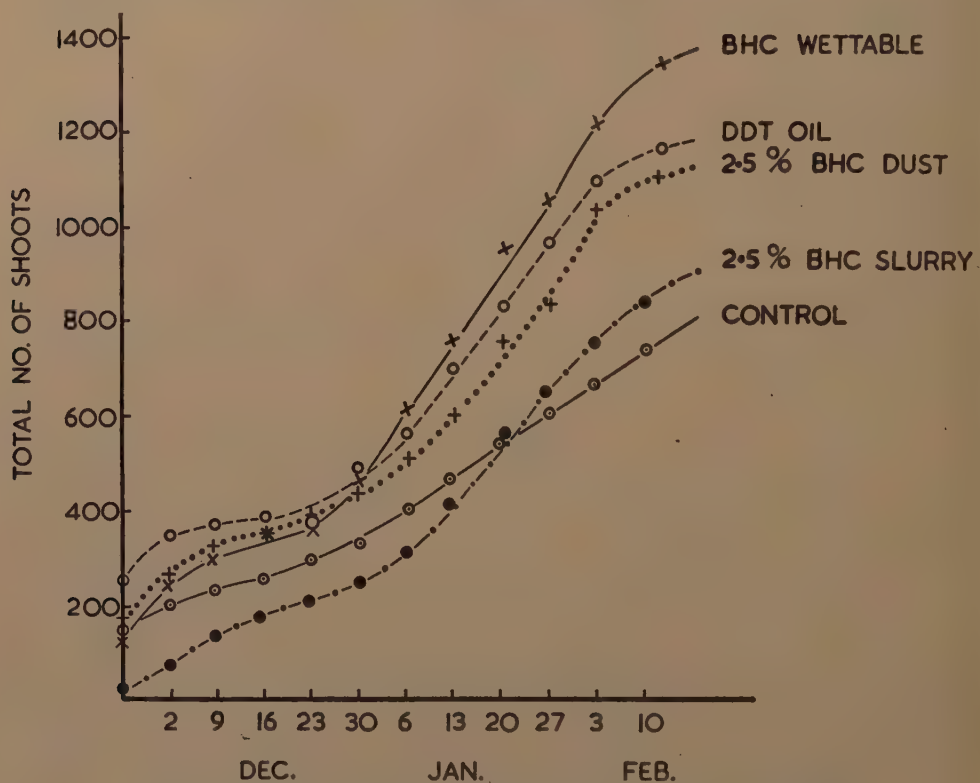


Fig. 6.—Weekly counts of the number of shoots produced by cane setts treated with γ BHC and DDT at time of planting.

The number of shoots per foot run of furrow at the end of the three-month period are shown in Table IV.

TABLE IV.

Effect of insecticides on the establishment of sugar-cane in a highly infested field at Arusha Chini.

Block no.	No. of shoots per ft. run of furrow after 3 months				
	Control	DDT (oil)	BHC (wetable)	BHC (dust)	BHC (slurry)
1	·89	5·92	5·83	5·96	1·58
2	·89	2·56	3·78	6·63	2·96
3	4·88	8·22	5·66	5·46	6·78
4	4·42	5·52	9·31	4·78	5·82
5	6·03	6·43	8·22	4·05	2·47
Mean	3·42	5·73	6·56	5·38	3·92 S.E. 0·9125

Least significant difference 2·70.

Lay out: 5 randomised blocks, 5 treatments. Variety: P.O.J. 2878.

Planted: November 1947. Last count of shoots: 10th Feb. 1948.

Owing to the variations introduced by the wide separation of blocks which were in different fields, and by the marked phytotoxic action of the BHC when applied as a slurry, the whole experiment was not significant with respect to error.

A final count in this trial was made after five months when the shoots were graded according to the following system:—I, shoots over 4 ft. high; II, from 2-4 ft; III, under 2 ft.

Owing to the development of salt in three of the blocks, the final results are not suitable for statistical analysis, but the following figures represent the total shoot production from the two remaining normal blocks.

TABLE V.

Effect of insecticides on the establishment of sugar-cane in a highly infested field at Arushi Chini.

	Total shoot production from two normal blocks after five months			
	Grade I	Grade II	Grade III	Total
Control	182	112	33	327
2.5% γ BHC, dust ..	151	129	95	375
2.5% γ BHC, slurry ..	256	119	77	452
BHC, wettable ..	376	46	51	473
DDT, oil	308	127	67	502

The only conclusion which can be drawn from these figures is that none of the chemical treatments was markedly phytotoxic and ^{low?} could safely be incorporated in larger-scale field trials.

The eventual choice of a 2.5 per cent. γ BHC commercial dust was made on the grounds of ease of application and of availability of a ready-formulated material. This treatment has been applied on the whole of the infested area of the estate as replanting was done. It has not been possible to carry out surveys of larvae in the area but the estate manager has stated (*in litt.*) that the yield of cane from these areas rose suddenly from 527 tons in 1946 to over 2,000 tons in 1948. The subsequent figures are shown in Table VI below. It has become the practice to treat all fields at planting time, and it is thought that adequate protection is offered for the virgin and the first ratoon crop. The figures in Table VI were given to the writer by the Manager of Arusha Chini estate, Mr. H. Hvidt.

The problem still remains of protecting the later ratoons, which should normally be the most profitable part of the rotation. It is suggested that a system of applying dusts of BHC, dieldrin or aldrin with the fertiliser be tried, or that aldrin or chlordane be used in miscible oil form, added to irrigation water. The laboratory findings of Wolcott (1951) in Puerto Rico, that 2 lb. of γ BHC or of technical aldrin killed even the largest grubs (*Cnemarachis portoricensis* (cited as *Phyllophaga*), a species of size similar to *Cochliotis*), may offer some indication, but field trials by the entomologist on the spot alone can provide the answer to this important aspect of white-grub control by chemicals.

Summary.

The principal pest of sugar-cane in northern Tanganyika is the Red Cane Beetle, *Cochliotis melolonthoides* (Gerst.) (MELOLONTHIDAE). Descriptions of

TABLE VI.
Crops of sugar-cane harvested after treatment with 2.5 per cent. γ -BHC dust.

Field no.	Area (acres)	Date planted	Virgin crop			First ratoon			Virgin crop when last replanted but without BHC. Tonnage per acre
			Date cut	Tonnage		Date cut	Tonnage		
				Total	Per acre		Total	Per acre	
14B	50	viii.48	ii.50	2785	55.7	vii.51	2616	52.3	30.3
12B	80	x.48	iii.50	3220	40.25	vii.51	3169	39.6	12
14A	67	ii.50	xi.51	5741	85.9	i.53	3107	38.8	20.1
13	100	iii.50	x.51	6076	60.7	i.53	3190	31.9	12.7
15A	15	iii.50	xi.51	1459	97.2	ii.53	820	54.7	8

No. 12B, second ratoon, cut xi.52, total tonnage 2121 and cane per acre, 26.5 tons.

adults and larvae of *Cochliotis* and of allied beetles found in the same area are given.

The bionomics of *Cochliotis* have been studied in the field over two seasons. The life-cycle is annual with adult swarming in early October and a season of maximum larval damage in July–August.

The intensity of infestation and the nature of the losses are discussed, and the mortality factors which act upon *Cochliotis* in nature are reviewed.

Cultural control measures suggested include the deferment of planting until July to October, when larval activity has waned; introduction of quick-maturing varieties, mechanically cultivated so that long ratooning can be gradually eliminated; regulation of the water table by control of irrigation, and the trial of resistant varieties. The Mauritius varieties M. 134/32 and M. 165/38 are suggested in this connection.

Biological control is discussed and a review of the parasite species that might possibly be introduced is made largely from the writer's Mauritius work on *Clemora smithi* (Arr.).

Experiments in the chemical control of *Cochliotis* are described and the final recommendation is the application at planting of $\frac{1}{4}$ lb. per 50 ft. of furrow of a BHC powder containing 2.5 per cent. of γ BHC. This practice has been adopted by the infested estate with successful results in virgins and first ratoons.

Further work is suggested on the chemical protection of second and later ratoons by surface application of BHC or aldrin.

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I wish to thank Mr. H. Hvidt, General Manager, and Mr. Madvig, Field Manager of the Tanganyika Planting Company, for their ready co-operation and help at all times. Mr. R. W. R. Miller, Director of Agriculture, Tanganyika, during the progress of the work, gave the writer every encouragement in conducting the investigations.

References.

- GERSTAECKER, F. (1867). Arch. Naturgesch., **33**, p. 41.
- JEPSON, W. F. (1936a). A summary of the results of the *Phytalus* investigation 1933–36 with recommendations as to further lines of work. . . .—19 pp. Port Louis, 1936.
- JEPSON, W. F. (1936b). Report on the search for parasites for *Phytalus smithi* Arr.—66 pp. Port Louis, 1936.
- MOUTIA, L. A. (1940). Bull. ent. Res., **31**, pp. 193–208.
- MUNGOMERY, R. W. (1951). 51st Rep. Bur. Sug. Exp. Stas Qd., 1950–51, pp. 39–47.
- WOLCOTT, G. N. (1951). J. econ. Ent., **44**, pp. 58–60.

LARGE-SCALE SPRAYING OF COTTON IN THE GASH DELTA IN EASTERN SUDAN.

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Large-scale spraying with DDT was first carried out in the Sudan in 1945 on the cotton of the Sudan Plantations Syndicate. The results of these experiments were described by Cowland & Edwards (1949). During the succeeding years evidence was accumulated of the beneficial effect on yield of this practice and the results of commercial spraying of large areas in the Gezira were examined by Snow & Taylor (1952). This analysis showed that the continued increases in the area of cotton sprayed which occurred between the years 1946 and 1950 was fully justified by the increase in yield which could be demonstrated from the yields from sprayed and unsprayed areas. In the season 1950/51 nearly 163,000 feddans* of cotton were sprayed in the Sudan Gezira and the overall increase in yield was estimated at 0.76 kantars † per feddan (Snow & Taylor, *op. cit.*).

These important benefits to be derived from spraying with DDT did not pass unnoticed by private growers and by 1952 the area of cotton, irrigated from the Blue and White Niles and sprayed with DDT against Jassids, was probably nearly 300,000 feddans.

Cotton cultivation in the Gash Delta has been described by Richards (1950). Here areas varying between 20,000 and 70,000 feddans of cotton are grown annually by means of controlled flush irrigation from the river Gash, an erratic and seasonal torrent. The flood arrives between June and July and continues for 68 to 110 days, the water being led by canals to discharge on to irregular areas of land through field watering channels termed *misga*. The area watered by a *misga* may vary from a few hundred to several thousand feddans. The watering period varies from 10 to 30 days and cotton is sown as soon as the land is sufficiently dry. This is usually during August but sowing continues into September. The early-sown cotton is usually X1730A and is known as first rotation cotton, and the late-sown cotton is usually Domains Sakel and is known as second rotation cotton. Picking begins in January and continues into May, but the crop receives no further irrigation after the pre-sowing watering. Watered land is allocated in ten-feddan holdings, and tenancies may be as large as 50 feddans. Yield figures can be obtained only from holdings representing an irregular number of tenancies. Further information on the system of cultivation practised in the Gash Delta can be obtained from E. Mackinnon (*in* Tothill, 1948), and on the climate of the Gash Delta from A. W. Ireland (*ibid.*).

Systematic observations on the incidence of insect pests in the Gash Delta began in 1945 and are recorded in the Annual Reports of the Research Division, Ministry of Agriculture 1945-1953. Amongst leaf-feeding insects the Cotton Jassid, *Empoasca lybica* (de Berg.), and the Cotton Flea-beetle, *Podagrica puncticollis* Weise, and the cotton thrips, *Hercothrips fumipennis* Bagn. & Cam. and *H. sudanensis* Bagn. & Cam., are annually responsible for severe damage, sometimes over widespread areas, and throughout the whole period of vegetative growth. Observations indicate that all this damage can be attributed to the multiplication within the crop of immigrants which have largely completed their

* One feddan = 1.038 acres = 0.42 hectare.

† One kantar = 315 rotls = 312 lb. of seed cotton yielding approx. 100 lb. lint of Domains Sakel and 107 lb. of X1730A.

invasion of the crop by mid-October. Experience of Jassid control in the Gezira, therefore, encouraged the belief that a single application of DDT, if applied over a wide enough area during the second half of October, would result in the eradication of these insects as pests of cotton for a whole season. Nevertheless bollworms, amongst which *Diparopsis watersi* (Roths.) was most serious, were regarded as being of far greater economic importance than the leaf-feeding insects, and the study of the status and control of bollworm had taken first place in entomological investigations. In 1951 a research team headed by J. Tunstall was appointed to investigate the biology and control of bollworms in the Gash Delta, paying particular attention to *D. watersi*. One of the field experiments carried out by this team was of randomised block design in which the effect on the pest complex of single and repeated applications of DDT was investigated. This experiment demonstrated the benefit in vegetative growth which cotton in the Gash might derive from the application of DDT. Cropping was advanced by spraying and although the sprayed treatments did not eventually yield significantly more cotton than the unsprayed treatments this was attributed to water shortage which was the major factor limiting yield in the area covered by the experiment.

As a result of this experiment, the Management of the Gash Board, influenced by the knowledge of the benefits derived in the Gezira from DDT spraying, decided to carry out spraying on a large scale in the season 1952/53. The reasons for this decision were not all purely agricultural although the scale of the spraying programme proposed was determined by the fact that if areas of more than a few feddans are sprayed in the Gash Delta, spraying can only be carried out by aircraft, and this involves the application of treatments to very large areas. A contract was therefore made for DDT spray to be applied to 80 per cent. of

TABLE I.
Distribution of treatments (in feddans).

Station	Misga	Unsprayed (I)	Sprayed once (II)	Sprayed twice (III)	No. of repli- cates
Kassala ..	Tugrar Rabakasa	288 —	450.5 661.5	252 —	1
Mekali ..	S I Baroka 8, 9, 10	133.5 154 —	264.5 817 3223	203 285 —	
Degein ..	4 and 5 Habacit 24—33	391.5 532	925 1930.5	282 654	1
Tendelai	11 6 Misga 1 west	896.5 670 109	2625.5 1781.5 366.5	725.5 401 244	6
Metateib ..	4/5 18 27	664 567.5 417.5	1908 723 935.5	592 489.5 418	5
Hadaliya ..	Bahabini 1 east Shabash 10 A	183 617.5 1620	469 1789 3420	168 616 1311	8
Total ..		6884	22299	6740	23

the cotton included in the first rotation. Three-quarters of this area were to be sprayed once and one-quarter twice.

The experiments in 1951 were carried out under conditions of very low population levels of bollworms. No evidence had been obtained to suggest that bollworms had been controlled by the spray treatments and the writer was concerned lest the proposed large-scale application of DDT would result in a substantial increase in losses from bollworm. The Management therefore kindly arranged, at considerable inconvenience to themselves and to the contractors, for the spraying to be carried out in such a way as to allow eventual statistical analysis of the yields from once- and twice-sprayed and unsprayed areas, and gave facilities for a team to collect data on the effect of spraying on major pests.

Layout of Treatments.

In 1952, the Gash flood was a large one and nearly 40,000 feddans of cotton were sown on the first rotation watering. The distribution of once-sprayed, twice-sprayed and unsprayed areas was decided by the Manager in consultation with the writer. The three treatments were distributed in Kassala, Mekali, Degein, Tendelai, Metateib and Hadaliya, in each station about 60 per cent. of the first rotation cotton being sprayed once, 20 per cent. twice and 20 per cent. left unsprayed. The allocation of the three treatments within a station was in units from which picking returns could be obtained, and it was possible to place the treatments on to 80 such holdings. The experiment can be visualised as one in which three treatments were randomised and replicated 23 times in stations scattered throughout the Gash Delta (Table I).

The first spraying took place between the end of October and mid-November, over a period of 24 days. The second spraying took place early in January over a period of five days. All spraying was by aircraft (Auster J.5G) at a dosage of 1 lb. technical DDT (as Psyllortox 250) in 2 gals. of spray per feddan.

Observation areas, each consisting of five feddans, were established in five of the stations. The distribution of treatments on these observation areas is shown in Table II.

TABLE II.

Distribution of observation areas on treatments.

Station	Observation Areas		
	Un-sprayed (I)	Sprayed once (II)	Sprayed twice (III)
Mekali	1	1	1
Degein	1	1	1
Tendelai	1	1	1
Metateib	3	3	3
Hadaliya	4	4	4

In each observation area the records of the incidence of important insect pests of cotton were kept and the following account is an analysis of the data recorded.

Effect of Spraying on Leaf-feeding Insects.

Cotton Jassid.

In each observation area, counts of Jassid nymphs on 500 leaves were made, five leaves being examined from each of 100 plant-holes scattered at random in the area. Counts were made just before spraying and at 15-day intervals after spraying until just after the second application of spray, when numbers had declined in all treatments to such an extent that they could no longer be considered an important pest affecting yield. Results are summarised in Table III. The general infestation throughout the delta was low compared with that usually encountered in the Gezira. Only in the western areas of Metateib were there large numbers and only here was Jassid damage conspicuous. The first spray gave an excellent control of the population present and differences in Jassid numbers and leaf vigour in sprayed and unsprayed treatments were apparent for 60 days after spraying. The second application of spray had no measurable effect on the small numbers then present.

Cotton thrips.

Thrips infestation was assessed as the number of leaves infested by adults or larvae in a 500-leaf sample taken at the same time as that for Cotton Jassid. Important pre-spraying infestation, chiefly *H. fumipennis*, existed only in Mekali and Degein. These were controlled by the first spray. There was no outbreak of *H. sudanensis* on any treatment during the season.

TABLE III.

Incidence of leaf-feeding insects.

(Numbers of nymphs of *E. lybica* per 100 leaves: percentage of leaves infested with *Hercothrips* spp. and numbers of adult *P. puncticollis* per 100 plant-holes.)

	Jassids	Thrips	Flea-beetles
Mean pre-spray numbers	55	6	104
Mean post-spray numbers :			
Unsprayed	54	18	333
Sprayed	4	3	324

Means of counts taken before spraying and at 15-day intervals for ten weeks after spraying. Counts of *E. lybica* are the means of all stations, and of *Hercothrips* spp. and *P. puncticollis* the means of two infested stations.

Cotton Flea-beetle.

These were recorded at 15-day intervals as the number of adult beetles per 100 plant-holes. Small numbers were present at all stations throughout the season and few leaves, except the youngest, in any plant-hole, were completely without damage. Numbers suitable for assessment of spraying existed, however, only in Mekali and Degein, and the mean pre- and post-spray counts in these stations are given in Table III. Fifteen days after spraying, numbers on the sprayed treatments were as great or greater than in the unsprayed. By the end of January, namely after the second spray, numbers in all observation areas were low and counts were stopped.

Effect of Spraying on Bollworm.

Attention was concentrated in Hadaliya where, during January, February and March, samples consisting of 360 plants, ten being collected from each of the three treatments in each of four observation areas, each month, were examined for bollworms in the following manner. First, the total number of fruiting nodes was counted; secondly, all existing fruit was collected in a bag for later examination and classification into buds, young and green bolls (the latter of a diameter of more than 15 mm.) damaged and undamaged by bollworms. The number and species of living bollworms, *D. watersi* and *Earias insulana* (Boisd.), collected was also recorded. Thirdly, a sample of 200 fresh sheds was collected in the observation area and classified as buds, young and green bolls damaged and undamaged by bollworms.

Similar observations were made on observation areas in the four other stations but by means of smaller samples.

Incidence of living larvae.

The most direct measure of the effect of spraying on bollworm numbers is by the determination of larval populations. This was estimated from the stripping data as the number of larvae per plant. The mean number of plants per feddan in over 120 sample counts in observation areas was about 10,000, so that the larval population per feddan can easily be estimated. The bollworm populations in January, February and March are summarised in Table IV. The two stations Metateib and Hadaliya are given in detail, but the means include data collected from Mekali, Degein and Tendelai also.

TABLE IV.

Populations of bollworms per plant (means of stations).

Station	Month	<i>Diparopsis watersi</i>			<i>Earias insulana</i>		
		I	II	III	I	II	III
Metateib	Jan.	1.5	2.3	2.6	1.9	1.5	1.2
	Feb.	1.0	0.8	0.9	0.9	1.4	0.6
	Mar.	0.2	0.6	0.05	0.05	0.05	0.0
	Sum	2.7	3.7	3.55	2.85	2.95	1.8
Hadaliya	Jan.	0.5	1.3	1.6	0.2	0.8	0.9
	Feb.	0.6	1.3	1.4	0.2	0.5	0.5
	Mar.	0.9	1.3	1.0	0.4	0.5	0.5
	Sum	2.0	3.9	4.0	0.8	1.8	1.9
Mean of all stations	Jan.	0.8	1.3	2.2	0.8	1.2	1.1
	Feb.	0.8	1.2	1.8	0.6	0.9	0.6
	Mar.	0.8	1.2	1.0	0.2	0.3	0.4
	Sum	2.4	3.7	5.0	1.6	2.4	2.1

I = unsprayed; II = sprayed once; III = sprayed twice.

Only Hadaliya figures were suitable for detailed statistical analysis. This is summarised in Table IVa.

In the Hadaliya observation areas the larvae of *D. watersi* were significantly more numerous in sprayed than in unsprayed areas in each month of observation.

The larvae of *E. insulana* were similarly more numerous in sprayed areas in January and February. In January, the numbers of both species were greater in areas sprayed twice than in areas sprayed once.

TABLE IVa.

Hadaliya station, bollworms per 100 plants (analysis of data from Table IV).

Month	<i>Diparopsis watersi</i>				Least significant difference $P=0.05$
	I	II	III	S.E.	
Jan. ..	50	132	163	± 5.6	19.4
Feb. ..	61	130	141	± 4.5	13.5
Mar. ..	89	128	100	± 13.6	33.9

Month	<i>Earias insulana</i>				Least significant difference $P=0.05$
	I	II	III	S.E.	
Jan. ..	23	79	91	± 2.4	10.8
Feb. ..	19	53	53	± 1.7	5.2
Mar. ..	41	49	50	± 3.2	9.4

I = unsprayed; II = sprayed once; III = sprayed twice; S.E. = standard error.

A similar analysis was made of the total numbers of larvae of *D. watersi* and *E. insulana* recorded in all observation areas during all the months of observation. This is summarised in Table V.

TABLE V.

Bollworms per 100 plants (total number recorded in all stations during December, January, February and March).

	I	II	III	S.E.	Sig. diff.
<i>D. watersi</i>	284.3	407.3	552.1	± 10.5	29.5
<i>E. insulana</i>	176.2	263.9	231.2	± 8.5	24.4

I = unsprayed; II = sprayed once; III = sprayed twice; S.E. = standard error; Sig. diff. = significant difference at $P = 0.05$.

The results from all stations were similar to those from Hadaliya, but the total numbers of *D. watersi* recorded were greater in areas sprayed twice than in areas sprayed once. There were also more larvae of *E. insulana* in sprayed than in unsprayed areas, but numbers in areas sprayed twice were significantly less than in areas sprayed once.

The mean number of *Diparopsis* larvae recorded in the two spray treatments during the whole period of assessment was nearly 70 per cent. greater than that recorded on unsprayed cotton during the same period. Similarly, over 40 per cent. more *Earias* larvae were recorded on sprayed than on unsprayed cotton.

Incidence of bollworm damage.

This is expressed as the total number of fruiting points per plant showing bollworm damage, together with the total number of fruiting points shed in association with bollworm damage (Table VI). No attempt was made to distinguish between damage by *Diparopsis* and *Earias*.

TABLE VI.

Sum of the monthly mean number of fruit points per plant damaged by bollworm during January, February and March.

	Unsprayed	Sprayed once	Sprayed twice
Damaged fruit per plant ..	15.5	18.2	18.1
Shed fruit damaged by bollworm	89.6	117.5	118.8
Total fruit lost by bollworm ..	105.1	135.7	136.9

Least significant difference for comparing the total fruit lost in association with bollworm damage is 13.8.

Increased numbers of damaged fruit per plant in sprayed as against unsprayed treatments were recorded in all stations except Metateib, where damage was similar. The sum of the monthly means of damaged fruit was 17 per cent. greater in sprayed than unsprayed treatments. In all stations, shed fruit damaged by bollworm was more numerous in sprayed than unsprayed treatments, and the total number of sheds recorded showing bollworm damage was 32 per cent. greater in sprayed than unsprayed cotton. The sum of the mean estimated monthly loss of fruiting points associated with bollworm attack was also 30 per cent. greater on sprayed than on unsprayed cotton.

The latter figure is significant at the 5 per cent. level and is consistent with the increase in numbers of bollworm found in sprayed treatments.

Incidence of damage to mature bolls.

The loss of buds and young bolls from bollworm attack is not necessarily reflected in yields. To assess the effect of bollworm on yield in the three

TABLE VII.

Survey of infestation of green bolls.

Sums of the average monthly total of bolls per plant during January, February and March 1953.

	Un-sprayed	Sprayed once	Sprayed twice	S.E.
Healthy mature bolls	46.0	38.7	42.8	± 3.3
Damaged mature bolls	10.7	13.3	14.6	± 1.7
Damaged by <i>D. watersi</i>	8.1	10.5	11.1	± 1.5
Damaged by <i>E. insulana</i>	2.6	2.8	3.5	
Total	56.7	52.0	57.3	± 2.0

treatments, samples of 50 nearly mature bolls were taken at random from each of the 30 observation areas during December, January, February and March, the numbers of such bolls per plant being counted at the same time. Thus 10 samples were taken from each of the three treatments, these being scattered in the five stations. The results, expressed as the sum of the monthly average per treatment in each station, are given in Table VII.

The differences in total number of mature bolls recorded in the three treatments are not significant. The number of damaged mature bolls was greater in the sprayed than in the unsprayed treatments, the increase being mainly in that attributed to *Diparopsis*. The total number of damaged bolls per plant during these months was 10.7 in unsprayed and 14.0 in sprayed, an increase in damage in sprayed treatments of 30 per cent. The differences, however, are not significant at the 5 per cent. level.

Effect of Spray on Plant Growth.

The effect of spraying on plant growth was recorded by means of plant diagrams constructed during January, February and March from ten plants, selected at random each month, from each of the treatments in the 12 observation areas in Hadaliya. Plant diagrams were also made similarly, but during February only, of similar samples from each of the 18 observation areas in Mekali, Degein, Tendelai and Metateib. The results for Hadaliya station are summarised in Table VIII.

TABLE VIII.

Effect of spraying on plant growth, Hadaliya station.

	Unsprayed	Sprayed once	Sprayed twice	Least sig. diff.
Sympodial branches	14.7	21.9	21.2	5.2
Fruiting nodes	46.7	79.6	71.9	18.5
Nodes per branch ..	3.1	3.6	3.4	—
Flower buds	11.0	24.5	16.0	—
Bolls (young)	14.4	20.0	19.0	—
Open bolls	2.6	3.1	3.6	—
Empty nodes	18.7	32.0	33.3	12.6
Total fruit	28.0	47.6	38.6	10.4
% empty nodes	40.0	40.2	46.7	—

Mean numbers per plant from plant samples from each treatment, 40 being taken from each treatment during each of the months January, February and March 1953.

During January, February and March the samples from the unsprayed observation areas contained significantly fewer sympodial branches, fruiting nodes and empty nodes than the sprayed treatments. On the other hand there was no difference in these characters between the two sprayed treatments. The mean

increase recorded in sprayed over unsprayed treatments taken as the cumulative total over the three months under review were as follows:—

	Increase (%) of sprayed over unsprayed.			
Sympodial branches	47
Fruiting nodes	62
Total fruit	54
Empty nodes	74

If plant growth in the 12 observation areas in Hadaliya was typical of that in the sprayed and unsprayed treatments in the commercial area, a considerable improvement in plant growth and potential yield might prove to be attributed to spraying. The increase in the total number of fruit however, recorded in the sprayed as compared with the unsprayed treatments was largely accounted for by buds and immature bolls, both damaged and undamaged being recorded in the plant diagrams. In the analysis previously made (Table VI) the mean number of damaged fruiting points recorded per plant during January, February and March was 17 per cent. greater on the sprayed than on the unsprayed treatments. Any increased fruit production in the sprayed treatments was therefore rapidly destroyed by *Diparopsis* and the total number of open bolls recorded in the sprayed treatments during these months was not significantly greater than in the unsprayed.

The greater fruit production in sprayed than in unsprayed cotton recorded between January and March in the samples from the Hadaliya observation areas was not so clear in the samples taken in February only from observation areas in the remaining stations. Nevertheless, in four stations out of five the samples from the sprayed treatment showed, as at Hadaliya, a greater number of fruiting nodes, a greater number of fruit and a greater number of sheds per plant. This tendency is summarised in Table IX.

TABLE IX.

Effect of spraying on plant growth, February 1953 (means per plant).

		Hadaliya	Metateib	Tendelai	Degein	Mekali	Mean
Fruiting nodes	Unsprayed	57	61	87	79	132	83
	Sprayed	60	76	108	79	141	93
Total fruit	Unsprayed	36	28	49	22	58	38
	Sprayed	42	29	50	27	44	38
Empty nodes	Unsprayed	14	33	38	57	74	43
	Sprayed	28	47	58	50	97	56

Effect of Spraying on Yields.

Figures showing the effect on yields are given in Table X, and, to see whether the effects of spraying might vary from place to place, the stations Hadaliya, Metateib and Tendelai were considered separately; the results from Degein, Mekali and Kassala were too few to be treated in this way and were bulked.

In each of the four analyses the effect of treatments failed to reach a significant level.

Although none of the differences between treatments reached a significant level "sprayed twice" often seemed lower than the other two treatments.

Accordingly it was decided to test average effect of the treatments over all districts. Due to various differences, including their large error which would have invalidated the analysis, Degein, Mekali and Kassala were omitted from this test.

TABLE X.
Yields in kantars per feddan.

Station	I	II	III	S.E.
Hadaliya ..	0.74	0.67	0.57	0.13
Metateib ..	1.15	1.07	0.79	0.28
Tendelai ..	1.40	1.32	1.08	0.14
Degein ..	1.86	1.37	1.53	} 0.45
Mekali ..	1.72	1.50	1.44	
Kassala ..	1.86	2.58	2.14	
Average of first 3 stations	1.10	1.02	0.81	0.105

I = unsprayed; II = sprayed once; III = sprayed twice;
S.E. = standard error of treatment mean.

Simple arithmetic average of the treatments for the remaining districts were 1.02, 0.81 and 1.10 k.p.f. for sprayed once, sprayed twice and unsprayed treatments, respectively (Table X). The significant differences (at 5% level) for comparing these mean yields is 0.24 k.p.f. The areas receiving two sprays yielded significantly less than the areas not sprayed.

Discussion.

The danger of increased bollworm damage to cotton by insecticides is widely recognised and the importance of this phenomenon in South Africa has recently been emphasised by Naude (1950). It is nevertheless difficult to produce in small-scale experiments the situation which occurs in the field following wide-spread application of insecticide and so measure the effect on bollworm. In the present work, three separate methods of assessment of the effect of spraying on bollworm have been employed. These have shown that, in a series of observation areas:—

- (i) the number of living larvae of *D. watersi* recorded between December and March, the period which covers maximum fruit production in the Gash Delta, was nearly 70 per cent. greater in sprayed than in unsprayed cotton. This difference was significant at 5 per cent. level of probability.
- (ii) the estimated total number of fruit damaged by, or shed in association with, bollworm attack, recorded between January and March was over 30 per cent. greater on sprayed than unsprayed cotton. This difference was significant at 5 per cent. level of probability.
- (iii) between December and March almost 30 per cent. more nearly mature bolls were found damaged by bollworm on sprayed than on unsprayed cotton, although this difference could have been due to chance.

The spray treatments killed Jassids and thrips, and sprayed cotton produced more sympodial branches and more fruiting nodes than unsprayed cotton. At the

same time, more fruits were shed, mostly in association with bollworm damage, on sprayed than unsprayed cotton, so that finally the sprayed plants obtained no benefit from the increased reproductive vigour. In some sites, so rapidly were young buds shed that the resultant short internodes of the sympodia gave the plant a distorted appearance. To what extent the greater fruit production of sprayed cotton can be attributed to increased vegetative vigour from spraying or to increased loss of fruit by shedding cannot be determined by the data.

The Gash crop is extremely irregular, due to unusually great variation in soil, rainfall, watering, sowing date, plant populations, standard of cultivation, etc. The observation areas represented a sample of 150 feddans from a total of nearly 36,000 in the experiment. Moreover, plant samples were of necessity small, the largest one being less than 0.004 per cent. of the total plant population of the station. Any attempts to correlate data from observation areas with station yields must therefore be extremely tentative. In Tables XI and XII are summarised some data on bollworm from observation areas within those stations which showed significant differences in yield.

TABLE XI.

Certain data from observation areas and mean yield of stations.

Station	Total living larvae of <i>Diparopsis</i> recorded per plant in monthly samples January to March			
	Unsprayed	Sprayed once	Sprayed twice	
Hadaliya ..	2.00	3.90	4.04	S.E. 0.267
Metateib ..	2.79	3.67	3.55	
Tendelai ..	3.11	3.50	4.40	
Mean ..	2.63	3.69	4.00	
Station	Total <i>Diparopsis</i> -damaged nearly mature bolls per plant in monthly samples January to March			
Hadaliya ..	5.9	7.1	14.7	S.E. 0.684
Metateib ..	14.3	15.4	20.3	
Tendelai ..	5.7	4.9	10.0	
Mean ..	8.63	9.13	15.03	
Station	Yields in k.p.f.			
Hadaliya ..	0.74	0.67	0.57	S.E. 0.105
Metateib ..	1.15	1.07	0.79	
Tendelai ..	1.40	1.32	1.08	
Mean ..	1.10	1.02	0.81	

In the three stations, *Diparopsis* larvae were significantly more numerous in sprayed than unsprayed treatments, the least significant difference at 5 per cent. for comparing treatments means being 0.967 larvae. The total number of bolls damaged by bollworm recorded in samples between January and March were similar on cotton sprayed once but greater at 1 per cent. levels on cotton sprayed twice. The least significant difference at 1 per cent. for comparing these means is 4.45.

In order to investigate any association of these data, use was made of the technique of Analysis of Covariance. This enabled the covariance between two sets of results to be split into components due to stations, treatments and residual (eliminating stations and treatments). The correlation coefficients for treatment means and for the residual variation could thus be estimated. The following results were obtained from such an analysis of the data given in Table XI.

1. Yield (in k.p.f.) and total damaged bolls per plant.

(error)	$r = + 0.827$	Not significant at 5%
(treatment)	$r = - 0.981$	Not significant at 5%
2. Yield (in k.p.f.) and total *D. watersii* larvae per plant.

(error)	$r = + 0.405$	Not significant at 5%
(treatment)	$r = - 0.843$	Not significant at 5%
3. Living larvae and bollworm-damaged bolls per plant.

(error)	$r = + 0.454$	Not significant at 5%
(treatment)	$r = + 0.724$	Not significant at 5%

Although the coefficient (r) describing the correlation of yield on the total number of damaged bolls per plant recorded at the three stations between January and March did not reach significance, it was too large to be ignored. The positive

TABLE XII.

Certain data from observation areas, February 1953.

Station	Mean numbers of bolls per plant			
	Un-sprayed	Sprayed once	Sprayed twice	Least significant difference 5% (standard error)
Hadaliya ..	6.2	6.3	5.9	
Metateib ..	12.6	7.0	5.5	
Tendelai ..	22.5	20.5	18.5	
Mean ..	13.77	11.27	9.97	3.848 (1.064)

Mean number of fruiting nodes per plant				
Hadaliya ..	57.5	60.1	60.4	
Metateib ..	60.8	67.5	85.0	
Tendelai ..	87.5	112.0	104.0	
Mean ..	68.60	79.87	83.13	17.40 (4.811)

Mean number of empty fruiting nodes per plant				
Hadaliya ..	14.4	26.8	29.6	
Metateib ..	32.6	46.0	48.5	
Tendelai ..	38.0	53.5	62.5	
Mean ..	28.33	42.10	46.87	5.476 (1.515)

correlation of the residual variance (error r) may mean that there was a tendency for the plants having the better yield potential to be more attacked than those with a smaller yield potential, while the negative correlation of the effect of treatment (treatment r) suggests that yields were reduced as a result of increase in bollworm damage by the spray treatments. Similar tendencies were apparent when the data for living *Diparopsis* larvae were examined. However, if unsprayed cotton carried more mature bolls than sprayed cotton, whose fruit was shed as buds and young bolls, more bollworm-damaged bolls would be recorded on such cotton because of the tendency of buds to be shed more easily than bolls, carrying the larvae with them and for a tendency for larger bolls to be infested by older larvae which are less likely to be missed in counting. Further information was sought on the validity of this interpretation from the plant observation data collected from the three stations during February (Table XII).

Analysis of covariance of the data in Tables XI and XII gave the following results:—

4. Yield (in k.p.f.) and bolls per plant recorded in February.

(error)	$r = + 0.6445$	Not significant at 5%
(treatment)	$r = + 0.9050$	Not significant at 5%
5. Yield (in k.p.f.) and total fruiting nodes per plant in February.

(error)	$r = - 0.8742$	Not significant at 5%
(treatment)	$r = - 0.8387$	Not significant at 5%
6. Bolls per plant in February and total living *Diparopsis* larvae per plant recorded from January to March.

(error)	$r = + 0.6124$	Not significant at 5%
(treatment)	$r = - 0.9922$	Not significant at 5%
7. Fruiting nodes in February and total living *Diparopsis* larvae per plant recorded from January to March.

(error)	$r = - 0.8898$	Significant at 5%
(treatment)	$r = + 0.9999$	Significant at 1%
8. Empty fruiting nodes per plant in February and total *Diparopsis* larvae recorded from January to March.

(error)	$r = + 0.0315$	Not significant at 5%
(treatment)	$r = + 0.9999$	Significant at 1%
9. Empty fruiting nodes and bolls per plant in February.

(error)	$r = - 0.1715$	Not significant at 5%
(treatment)	$r = - 0.9954$	Not significant at 5%
10. Yield (in k.p.f.) and empty nodes per plant in February.

(error)	$r = - 0.3295$	Not significant at 5%
(treatment)	$r = - 0.8612$	Not significant at 5%

Considering first the correlations of the variance due to treatments, the following sequences are apparent: increased numbers of larvae were correlated with an increase in numbers of fruiting points (7); the more larvae, the more sheds (8), the more sheds the less bolls (9) and the more sheds the less yield (10). Conversely, the more bolls the more yield (4) and the less sheds the more bolls (9). Moreover, the more larvae the less bolls (6) but the more damaged bolls (3), and the more damaged bolls the less yield (1). Finally the less larvae the more yield (1).

This logical sequence of events, indicated by correlations not always significant but too large to be ignored, suggest the conclusion that spraying reduced yield

because it increased the number of *Diparopsis* which caused excessive shedding and damage to mature bolls. Such a conclusion would be inescapable if consistently supported by similar correlations in the residual variance. When variance due to site and treatment had been eliminated it could be shown that an increase in the number of *Diparopsis* larvae recorded was associated with a decreased production of fruiting points (7). But again removing variance due to site and treatment, the more larvae the more bolls (6) and the more yield (2), but the more damaged bolls (1). These are consistent but different from the previous conclusions.

These analyses are interpreted to indicate that *Diparopsis* lowered the yield potential of the crop, as expressed by fruit point production and boll retention, as a result of the continuous shedding of the fruit it damaged. *Diparopsis*, however, tended to attack cotton with the best yield potential. The effect of spray treatments was to increase the number of *Diparopsis* thus causing excessive shedding, increased production of fruiting points, increase in number of damaged bolls and reduced yields.

The simple correlation of yield on number of sprays just failed to reach significance ($r = -0.9774$), but suggests a negative regression of yield on numbers of sprays. The data analysed give strong support to the view that this adverse effect of spraying on yield was due to its demonstrated beneficial effect on *Diparopsis*.

Summary.

Following increased yields of cotton in the Sudan Gezira by DDT spraying, during the 1952/53 season 22,300 and 6,700 feddans of X1730A cotton were sprayed once and twice, respectively, in the Gash Delta of eastern Sudan, where nearly 60,000 feddans were grown under controlled flush irrigation. Each spray consisted of 1 lb. technical DDT per feddan and was applied by aircraft in 2 gals. of spray per feddan.

Systematic observations were made on the incidence of cotton pests in 30 observation stations scattered throughout the Gash Delta, such stations being selected more or less at random from cotton sprayed once and twice and unsprayed, ten amongst each of these three treatments.

A single DDT spray applied 50-70 days after sowing gave entirely satisfactory control of the Jassid, *Empoasca lybica* (de Berg.), and the thrips, *Hercothrips fumipennis* Bagn. & Cam. and *H. sudanensis* Bagn. & Cam., throughout the growth of the crop. There was little lasting control of the flea-beetle, *Podagrica puncticollis* Weise. The second spray, applied 70-90 days later, had little effect on any of these pests which were then present in low numbers.

The incidence of bollworms was observed between December and March, covering the important fruiting period. During these months, over 70 per cent. more larvae of *Diparopsis watersi* (Roths.) and 40 per cent. more larvae of *Earias insulana* (Boisd.) were observed on sprayed than on unsprayed cotton. Significantly more larvae of *D. watersi* were recorded on cotton sprayed twice than sprayed once; conversely, significantly fewer larvae of *E. insulana* were recorded on twice- than on once-sprayed cotton. Moreover the estimated total number of fruits damaged by or shed in association with bollworm attack between January and March was over 30 per cent. greater, and nearly 30 per cent. more bollworm damage to nearly mature bolls was recorded between December and March, on sprayed than on unsprayed cotton.

Yields of seed cotton were significantly less from twice-sprayed than from the other treatments. Once-sprayed cotton yielded less but not significantly so, than unsprayed cotton. Yield was negatively correlated with the number of sprays but the correlation coefficient just failed to reach significance.

Further analysis of the data from stations where yield differences were most

marked indicated that *D. watersi* lowered the yield potential of the crop as expressed by fruit production and retention, as a result of continuous shedding of the damaged fruit. Attack, however, was concentrated on cotton with the best yield potential. The effect of spraying was to increase the numbers of *D. watersi* and thus to give rise to excessive shedding, increased production of fruit primordia, an increased number of damaged bolls, and finally reduced yield.

It is concluded that any benefits which the crop enjoyed, as a result of elimination of leaf-feeding insects by DDT spray, were completely lost through increased bollworm attack, which moreover reduced the yield below that of unsprayed cotton.

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References.

- COWLAND, J. W. & EDWARDS, C. J. (1949). Control of *Empoasca lybica*, de Berg. on cotton in the Anglo-Egyptian Sudan.—Bull. ent. Res., **40**, pp. 83–96.
- NAUDE, T. J. (1950). Cotton-insect problems.—Fmg in S. Afr., **25**, pp. 349–351.
- RICHARDS, C. H. [1950]. The Gash Delta.—Bull. Minist. Agric. Sudan, no. 3, 56 pp.
- SNOW, O. W. & TAYLOR, J. (1952). The large-scale control of the Cotton Jassid in the Gezira and White Nile areas of the Sudan.—Bull. ent. Res., **43**, pp. 479–502.
- TOTHILL, J. D. Ed. (1948). Agriculture in the Sudan.—974 pp. London, Oxford Univ. Pr.
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NEW SPECIES OF AFRICAN STEM-BORING AGROTIDAE
(LEPIDOPTERA).

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This paper was originally intended to describe four species of Agrotid stem-borers from the Gold Coast that were not dealt with in a previous contribution (Tams & Bowden, 1953). I have recently had the opportunity of studying material from Southern Rhodesia and Uganda containing two undescribed species which are included here.

Three new genera have been erected which have several characters common to the rest of the stem-boring group of the AGROTIDAE; to avoid unnecessary repetition in generic definitions these characters are set out here. The proboscis is aborted and small. The palps are upturned in both sexes, reaching to about the midpoint of the eyes or to about the base of the antennae. The antennae are always simple in the female and the antennal setae short and fasciculate in both sexes. The eyes are large, more or less round, and bare. The tibiae are fringed with long hairs, particularly on the hind legs. Except in *Speia* Tams & Bowden the forewing is evenly rounded at the apex and the termen is not crenulate; vein 9 arises from vein 10 and anastomoses with vein 8 to form the areole, while vein 11 arises from the cell. In the hindwing vein 5 is imperfect and vein 8 arises near the base of the cell.

In the generic descriptions of *Sciomesa* Tams & Bowden and *Conicofrontia* Hampson in Tams & Bowden (1953, pages 648 and 651) it was stated that the thoracic vestiture consisted of hairs only; re-examination has shown that this is not so, the thorax being clothed with hair and hair-like scales*; it is therefore necessary to amend the descriptions of the two genera to read accordingly.

The opportunity is taken to revise the key to the genera included in the previous paper so as to accommodate those now described.

All the adults dealt with in the text were bred from immature stages collected in the host-plants mentioned. Type material of all the new species has been deposited in the British Museum (Natural History).

REVISED KEY TO GENERA.

1. Frons with pointed or rounded prominence 2
Frons without prominence, slightly or not inflated 5
2. Forewing with apex produced and acute, termen obliquely curved
Speia Tams & Bowden
Forewing with apex rounded, termen evenly rounded 3
3. Frons with large blunt prominence. Aedeagus with apical bulbed cornutus or spinose. Bursa copulatrix without signum ... *Poeonoma* Tams & Bowden
Frons with pointed or conical prominence 4

*The terms "hair" and "hair-like scale" refer to the up-standing thoracic vestiture and not to the adpressed scales that are found beneath the longer covering. The hair-like scale may always be distinguished by its flattened and bifurcate apex, as compared with the rounded or pointed apex of the hair. In some badly rubbed specimens it is not always easy to distinguish hairs and scales on the disc of the thorax, but examination of either the tegulae or epaulets, which are usually less rubbed and damaged, will show whether one or both types of vestiture are present.

4. Antenna of male bipectinate. Thorax with crest. Male genitalia with valve simple, no sclerotised processes present. Bursa copulatrix with signum *Sciomesa* Tams & Bowden
- Antenna of male serrate. Thorax without crest. Male genitalia with valve possessing two heavily sclerotised dentate plates. Bursa copulatrix without signum *Conicofrontia* Hampson
5. Thorax clothed with hairs only. Frons not inflated *Sesamia* Guenée
- Frons slightly inflated. Thorax clothed with hair and hair-like scales 6
6. Thorax with crest 7
- Thorax without crest 8
7. Antenna of male serrate. Costa of forewing straight. Male genitalia with cucullus simple, sacculus with clavus, juxta with paired protuberances. Female genitalia with heavily sclerotised plates at ostium ... *Carelis*, gen. n.
- Antenna of male simple. Costa of forewing convex. In male genitalia cucullus with stiff hairs on internal surface, sacculus without clavus, juxta simple. In female genitalia ductus bursae without sclerotised plates at ostium, ostium small and ovoid *Poecopa*, gen. n.
8. Antenna of male simple. Aedeagus without spinose processes at level of juxta. Bursa copulatrix with signum, ductus bursae not sclerotised, ostial segment not sclerotised *Manga*, gen. n.
- Antenna of male bipectinate or serrate. Aedeagus with spinose processes at level of juxta. Bursa copulatrix with signum, ductus bursae sclerotised, ostial segment sclerotised *Busseola* Thureau.

Carelis, gen. n.

Type species—*Carelis albula*, sp. n.

Frons slightly inflated but without prominence (fig. 1). Antenna of male serrate to apex. Thorax clothed with scales and hairs, prothorax with moderate crest, tegulae moderately developed but prominently crested, epaulets large. Abdomen without crests. Forewing with vein 3 from apex of cell; 4 arising near 5; 6 from upper angle of cell; 7 from distal angle of areole. Hindwing with veins 3 and 4 arising from lower angle of cell; 6 and 7 stalked from upper angle of cell.

Male genitalia: Tegumen with well-marked peniculi. Uncus long, slightly dilated at apex. Valve strongly quadrate; sacculus with a small clavus; cucullus small, conical, not separated from sacculus; costal margin strongly sclerotised, with a prominent sclerotised ridge-like expansion. Aedeagus short, inflated at base, manica membranous, vesica without cornutus. Juxta with paired dorsal protuberances. Vinculum moderately dilated with small saccus.

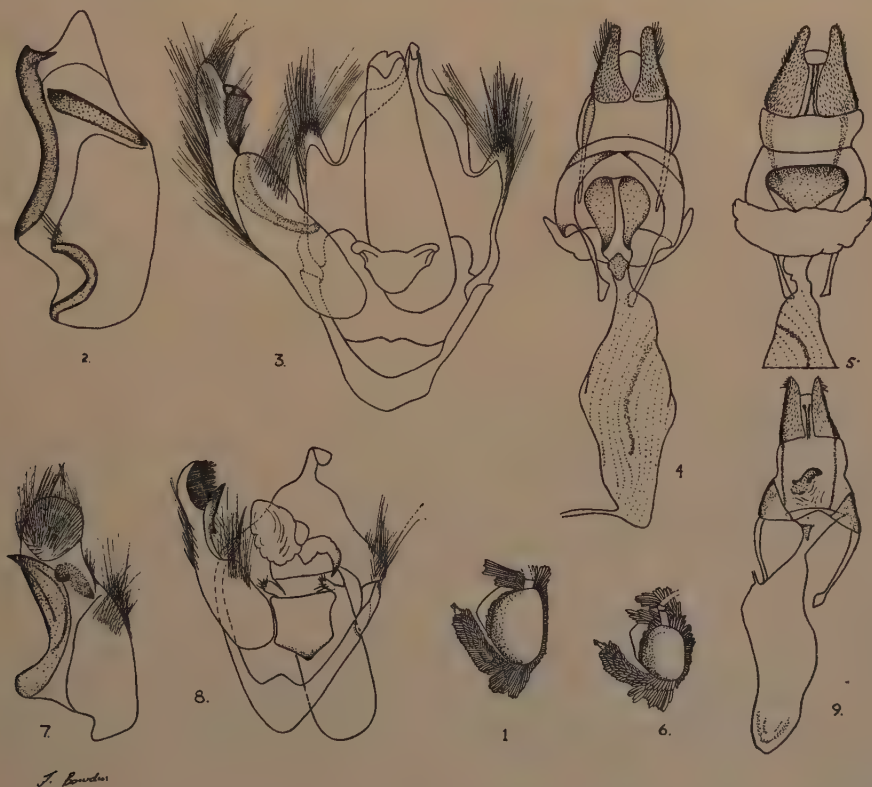
Female genitalia: Bursa copulatrix without signum; ductus bursae short, broad, with sclerotised plates at ostium; ductus seminalis from ductus bursae. Ostium broad with ventral lip moderately sclerotised. Ovipositor lobes small and bluntly pointed.

This genus is in many respects close to *Sciomesa*, particularly in the relatively simple genitalia of both sexes and in the wing venation. It is easily separated in both sexes by the inflated but not prominent frons. In the male genitalia, the presence of a small but distinct clavus and the dorsal processes of the juxta are further points of difference; the female genitalia agree with those of *Sciomesa* in the membranous ostial segment but differ by the absence of signa on the bursa copulatrix and the form of the sclerotisation of the ductus bursae.

Carelis albula, sp. n.

♂. Palpus pale, moderately infusate dorsally, lightly infusate ventrally. Antenna serrate to apex, antennal scaling chalk-white. Head pale, lightly to

moderately infusate, especially on vertex. Thorax pale; scales of tegulae with a subterminal fuscous band, of crest with a subterminal fuscous-black band, of epaulets entirely chalk-white. Pectus pale, very lightly infusate. Legs pale, foreleg lightly infusate on femur and tibia, tibia with moderately long fringe. Abdomen rather elongate, pale with light ochraceous-fuscous suffusion dorsally on first segment; anal tuft pale with light ochraceous-fuscous or fuscous suffusion. Forewing very pale with slight buff suffusion at base, with shining fuscous-buff suffusion towards termen; a chalk-white longitudinal fascia along lower margin of cell, within cell, and sometimes a discrete small chalk-white patch beyond apex of cell; a weakly defined antemedial dentate fuscous fascia, often obsolete from vein 8 except for a small fuscous patch on vein 1; a median discoidal fuscous or fuscous-buff suffusion extending from antemedial line to postmedial line, sometimes weakly defining orbicular and reniform spots; a weak postmedial fuscous fascia consisting of an oblique line to vein 8, thereafter continuing to inner margin as isolated fuscous spots on veins; a subterminal series of fuscous to fuscous-black interneural spots, fuscous-black and prominent from between veins 7 and 6 to between veins 4 and 3, fuscous and indeterminate or even absent between veins 3 and 2, and 2 and 1; a terminal series of small interneural fuscous or fuscous-black spots; termen broadly suffused fuscous or fuscous-black,



Figs. 1-5.—*Carelis albula*, gen. et sp. n. (1) ♂ head, scales removed from frons; (2) ♂ genitalia, ventral view of valve; (3) ♂ genitalia, ventral view; (4) ♀ genitalia, dorsal view; (5) ♀ genitalia, ventral view.
Figs. 6-9.—*Poecopa mediopuncta*, gen. et sp. n. (6) ♀ head, scales removed from frons; (7) ♂ genitalia, internal view of valve; (8) ♂ genitalia, ventral view; (9) ♀ genitalia, ventral view.

iridescent; fringe white, variably suffused fuscous-buff to fuscous-black. Hindwing white, iridescent, variably suffused pale fuscous-buff on disc. Underside of forewing suffused shining fuscous-buff, with a fuscous discal spot; a fuscous postmedial fascia from costa to inner margin; a terminal series of small inter-neural fuscous spots. Underside of hindwing as for forewing.

Expanse, 25-30 mm.

Male genitalia (figs. 2, 3) as for genus; clavus consisting of a sclerotised 'edge and a few small stiff hairs; sclerotised process of costal margin of valve with a prominent apical tooth.

Female similar to male, but usually considerably infusate, particularly on thorax, including epaulets; wings with variable fuscous flecking, fuscous markings more distinct, often fuscous-black or black, the medial chalk-white fascia thus appearing more prominent.

Expanse, 28-34 mm.

Female genitalia (figs. 4, 5) as for genus; bursa copulatrix long, pointed with fairly well-marked striations; ductus bursae with a small sclerotised area at about middle, the sclerotised plates at ostium drop-shaped; anterior margin of ostial segment folded back over ostium and considerably thickened.

♂ Type: GOLD COAST, Kwadaso nr. Kumasi, *ex Scleria verrucosa* (Cyperaceae), 5. vi. 1952. ♀ Allotype: GOLD COAST, Mile 15 Kumasi-Offinso Road, *ex Scleria verrucosa*, 20. vi. 1952. Paratypes: GOLD COAST, Kwadaso nr. Kumasi, 2♂♂, 3♀♀, 30. v.-16. vi. 1952, 1♂, 1♀, 19. ix. 1953; Mile 15 Kumasi-Offinso Road, 1♂, 2♀♀, 16-20. vi. 1952 (all *ex Scleria verrucosa*).

Carelis albula is a readily recognised species. The adults are distinguished from adults of other West African borers by their predominantly whitish appearance. The larvae have a characteristic habitat, *C. albula* being at present the only Agrotid borer in Africa known from the Cyperaceae, but they are so similar in appearance to those of *Sesamia* that the first larvae of *C. albula* to be found were reared as "*Sesamia* sp.". Apart from their habitat they may be separated by the chaetotaxy of the ninth abdominal segment; in *C. albula* seta L1 is distinctly forward of setae SD1 and L2, whereas in *Sesamia* these setae are more nearly in line.

Poecopa, gen. n.

Type species—*Poecopa mediopuncta*, sp. n.

Frons slightly inflated, but without prominence (fig. 6). Antenna of male simple. Thorax clothed with scales and hair, prothorax with prominent crest, tegulae small but moderately crested. Abdomen with small crests on first two segments. Forewing rather narrow with costal margin somewhat convex; veins 3, 4, 5 arise close together, 4 from lower angle of cell; 6 from upper angle of cell. Hindwing with veins 3 and 4 from lower angle of cell; 6 and 7 from upper angle of cell.

Male genitalia: Tegumen with small peniculi. Uncus large, widened just before apex. Valve short and broad; sacculus almost as wide as long, without clavus; cucullus broad, internal face with long stiff hairs; costal margin markedly concave, sclerotised, with a costal spine. Aedeagus short, stout, not inflated at base, manica membranous with paired ventral projections bearing stiff setae, vesica with curved basal cornutus. Juxta simple. Vinculum deep, rather pointed.

Female genitalia: Bursa copulatrix without signum; ductus bursae short with a lightly sclerotised area at base near ostium; ductus seminalis from base of bursa. Ostium small, ovoid, ostial segment not sclerotised but ventral lip of ostium slightly thickened. Ovipositor lobes with bluntly pointed apex armed with a row of stout recurved spines.

The affinities of this genus are difficult to determine. Its relatively simple genitalia, particularly those of the female, place it near *Sciomesa* but there the resemblance ends. The remarkable form of the cucullus of the valve in the male genitalia is unlike that of any other Agrotid borer and is a ready means of identification. The presence of processes on the male aedeagus is reminiscent of *Busseola* but cannot be taken to indicate a very close relationship. *Poecopa* must at present be regarded as a somewhat isolated genus.

***Poecopa mediopuncta*, sp. n.**

♂. Palpus pale yellowish-white, heavily infusate. Antenna simple, pale yellowish-white to pale cartridge-buff, lightly to moderately infusate. Head pale cartridge-buff to almost white, moderately to heavily infusate, the heavier infuscation being almost black with purplish gleams. Thorax pale cartridge-buff to ivory white, moderately to heavily infusate on anterior part, the heavier infuscation being almost black, with purplish or bluish gleams, epaulets sometimes suffused rufous as well as infusate. Pectus and pleura dingy white, pectus rather heavily infusate, this infuscation sometimes with purplish gleams. Legs dingy white, third tibia with fringe less heavily infusate, sometimes almost white; tarsi infusate with a pale yellowish apical ring to each segment. Abdomen dingy white, moderately to heavily infusate especially on dorsum, crests fuscous-black to black, anal tuft cartridge-buff. Forewing cartridge-buff to buff sometimes with considerable reddish-brown to rufous suffusion, in some lights even showing pink, costal margin sometimes also with purplish gleams; veins in anterior half outlined with pale cartridge-buff or slightly infusate-buff; a small but prominent chalk-white discoidal spot; some fuscous-black to black markings variable in extent and intensity, sometimes even absent; an irregular antemedial fascia confined to discal area; an irregular fuscous to fuscous-black suffusion or fascia around discoidal spot; a curved postmedian fuscous to fuscous-black fascia of interneural spots fading towards wing margins; an oblique fuscous to fuscous-black subterminal fascia from costal angle to about vein 3; a terminal series of interneural fuscous to fuscous-black spots; fringe very long with considerable fuscous suffusion at base, a median clear line sometimes with a rufous to pink suffusion apex irregularly infusate. Hindwing dingy white, heavily infusate, infuscation sometimes strongly iridescent; veins 3 and 4 sometimes with short stalk from lower angle of cell. Underside of forewing whitish-buff to cartridge-buff, moderately to heavily infusate, sometimes strongly iridescent; a terminal series of interneural fuscous to fuscous-black spots; fringe whitish, heavily infusate, with whitish-buff to cartridge-buff patches at vein endings, the tip of fringe sometimes with pink suffusion. Underside of hindwing dingy white, costal area suffused cartridge-buff to buff, otherwise moderately to strongly infusate, sometimes strongly iridescent; fringe cartridge-buff at base, white at apex with a narrow median fuscous line on terminal margin.

Expanse, 21–26 mm.

Male genitalia (figs. 7, 8) as for genus; rather small; tegumen steeply angled; cucullus rounded, or sometimes rather quadrangular, the stiff hairs on its internal surface bright golden in colour; costal spine curved, pointed; juxta shield-shaped.

♀. Very similar to male, slightly larger.

Expanse, 25–33 mm.

Female genitalia (fig. 9) as for genus; bursa copulatrix large; sclerotised area at base of ductus bursae triangular in outline.

♂ Type: GOLD COAST, Kwadaso nr. Kumasi, bred *ex Rottboellia compressa*, 25. vi. 1952. ♀ Allotype: GOLD COAST, Mile 19–20 Kumasi–Mampong Road, bred *ex Setaria chevalieri*, 26. ix. 1951. Paratypes: GOLD COAST, ♀ Mile 21 Kumasi–Mampong Road, 2. viii. 1951; ♀, Edwinase nr. Kumasi, 6. vii. 1952; ♂, Kwadaso nr. Kumasi, 8. vii. 1952; ♀, Mampong, 22. vii. 1953 (all bred *ex*

R. compressa); ♀, Mile 20–21 Kumasi–Mampong Road, 9. viii. 1951; ♂, Mile 19–20 Kumasi–Mampong Road, 20. ix. 1951; ♀, Obuobo, Kumasi–Offinso Road, 20. x. 1951 (all bred *ex Setaria chevalieri*; ♂, Mile 18 Kumasi–Mampong Road, 5. viii. 1952; Kwadaso nr. Kumasi, ♂, 10. ix. 1953, ♀, 14. ix. 1953; Kumasi, ♀, 7. ix. 1952, ♀, 5. vii. 1953, ♀, 15. x. 1953 (all bred *ex Pennisetum purpureum*); ♂, Foso, Gold Coast Colony, 25. ix. 1952 (bred *ex Sorghum arundinaceum*).

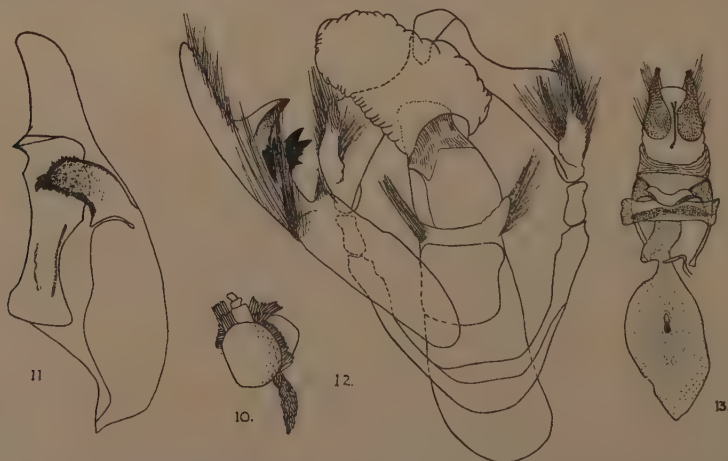
This little species is easily recognised by its characteristic wing markings, in which it bears a resemblance to the Palaearctic *Meliana geminipuncta* (Haw.). As a polyphagous species it is surprising that it has not yet been found in maize, although the latter frequently grows near infested grasses. Its importance at present is in the ease with which the pink larvae can be mistaken for those of *Sesamia*. The recorded localities have all produced *S. botanephaga* Tams & Bowden, in many cases in the same collection. The larvae of *P. mediopuncta* are separable from those of *Sesamia* spp. by seta L1 of abdominal segment 9 being set well forward of setae SD1 and L2, instead of being almost in line, and by the prominent pinnaculi, which also separate them (apart from host-plant differences) from those of *Carelia albula*.

Manga, gen. n.

Type species—*Manga basilinea*, sp. n.

Antenna of male simple. Frons inflated, without prominence (fig. 10). Thorax clothed with scales and hairs, without crests, but tegulae moderately crested. Abdomen without crests. Forewing with vein 3 from lower angle of cell; 4 and 5 close together; 6 from a little before apex of areole; 8 and 9 very long-stalked from areole. Hindwing with veins 3 and 4 close together from lower angle of cell; 6 and 7 long-stalked from upper angle of cell.

Male genitalia: Tegumen with moderate peniculi. Uncus short, broad. Valve elongate; sacculus narrow, without clavus, with a well-developed clasper;



Figs. 10–13.—*Manga basilinea*, gen. et sp. n. (10) ♀ head, scales removed from frons, palp displaced; (11) ♂ genitalia, internal view of valve; (12) ♂ genitalia, ventral view; (13) ♀ genitalia, ventral view.

cucullus long and narrow; costal margin broadly but lightly sclerotised, with a well-developed ridge-like expansion. Aedeagus short, stout, slightly dilated at apex, vesica membranous without cornutus, manica membranous with lateral hair tufts. Juxta simple. Vinculum shallow, rounded, with a moderate saccus.

Female genitalia: Bursa copulatrix with paired signa; ductus bursae broad, not sclerotised, sharply separated from bursa; ductus seminalis from junction of bursa and ductus bursae. Ostium ovoid, anterior lip indented; ostial segment not sclerotised but with a well-developed anterior fold. Ovipositor lobes small.

This genus resembles the *Sciomesa*-*Conicofrontia* group in the structure of the genitalia, but in other characters, such as the inflated but not prominent frons, it is nearer *Busseola*. It is separated from *Sciomesa* by the shape of the frons, the presence of a strong clasper in the male and the origin of the ductus seminalis in the female; and from *Conicofrontia* by the shape of the frons, the absence of a clavus in the male, and by the presence of a signum in the female. It is distinguished from *Busseola* by the form of the clasper and costal expansion in the male and by the unarmed ostial segment in the female.

***Manga basilinea*, sp. n.**

♂. Palpus light buff, infusate. Antenna simple with light buff to whitish scales, cilia short, fasciculate. Head pale cartridge-buff, streaked fuscous-brown to fuscous-black particularly on occiput. Thorax very pale buff, almost white, heavily streaked fuscous-brown to fuscous-black. Pectus infusate. Legs fuscous, tibial fringe pale buff, that on forelegs heavily streaked with fuscous, tarsi fuscous-black with a pale ring at apex of each segment. Abdomen light buff, heavily infusate. Forewing ochraceous-buff, heavily infusate along costa and in discal area, this infuscation terminating in an oblique line from apex to inner margin and outlining some buff fascia; a small basal fascia on costa; a well marked antemedial fascia, oblique from costa to below median vein, strongly recurved to vein 1, then bent sharply distad to inner margin; a postmedian spot on costa; orbicular and reniform spots outlined fuscous-black, the intervening area pale; a prominent basal fuscous-black longitudinal fascia ending below cell; a poorly defined oblique, dentate fuscous fascia defining discal margin of discal infuscation; an oblique fascia of fuscous-black spots on the veins from vein 6 to inner margin, some spots expanded proximally and bordered distally by pale buff; a terminal series of fuscous-black spots on the veins; termen rather heavily infusate; fringe pale buff heavily infusate at vein endings along termen and generally infusate from vein 3 to inner margin. Hindwing dingy white, heavily flecked with fuscous, veins outlined with fuscous-black. Underside of forewing dingy white or pale buff, heavily infusate in discal area, costa fuscous flecked with pale buff. Underside of hindwing pale buff to dingy white, moderately flecked with fuscous, veins outlined with fuscous-black.

Expanse—28 mm.

Male genitalia as for genus (figs. 11, 12); clasper heavily spinose.

♀. Similar to male; forewing less heavily infusate, the basal buff markings thus much less conspicuous.

Expanse—28 mm.

Female genitalia as for genus (fig. 13); bursa copulatrix short, rounded; ovipositor lobes somewhat dilated basally, their apices rather pointed with a few very small bristles.

♂ Type: GOLD COAST, Northern Territories, Nyankpala nr. Tamale, bred *ex Pennisetum* sp., 4. ix. 1952. ♀ Allotype: GOLD COAST, Northern Territories, Bawku, bred *ex* millet (*Pennisetum typhoides*), 10. ix. 1952. Paratype: ♂, GOLD COAST, Nyankpala nr. Tamale, bred *ex Pennisetum* sp., 2. ix. 1952.

This species is superficially similar to *Busseola fusca* (Fuller), from which it is at once distinguished by the prominent basal fuscous line of the forewing. The larva is unfortunately unknown. The allotype female was collected as a larva boring in a millet stem, and entered in my records as a *Busseola*; the males were both collected as pupae. It is a matter of some interest to establish the

status of this species, as there is a possibility that it may replace *B. fusca* in the far north of the savannah zone, since it is already known that in West Africa the latter species is less common in the northern areas of the Guinea Savannah and Sahel Zones (Tams & Bowden, 1953).

A solitary female apparently of another species of *Manga* is in my collection; it is thought advisable to wait until more specimens are found, including males, before describing it.

Calamistis nubifera Hampson (Cat. Lep. Phal. Brit. Mus., 9, p. 276, 1910) (**new comb.**), from the Belgian Congo, should be transferred to the genus *Manga*. It differs from *M. basilinea* by the absence of a basal fuscous line, and by the subterminal fascia being a buff line instead of a series of pale interneural spots.

Busseola Thurai.

The genus *Busseola* is a heterogeneous assemblage of species; few if any of those at present contained in it are congeneric with the type species *B. fusca* (Fuller). The three species described below undoubtedly belong to the genus as defined by Tams & Bowden (1953), but to accommodate them the previous generic description requires slight amendment.

Frons inflated, without prominence. Antenna of male short-bipectinate and serrate at apex or serrate. Thorax clothed with hair-like scales and hair, without crests, tegulae small but crested. Abdomen without crests. Forewing with vein 3 from lower angle of cell; 4 arising near 5; 6 and 7 from areole or 7 stalked from beyond areole; 8 and 9 sometimes stalked. Hindwing with veins 3 and 4 from lower angle of cell or 3 from just before lower angle; 6 and 7 stalked from upper angle of cell.

Male genitalia: Tegumen with peniculi small to prominent. Uncus simple. Valve broad; sacculus without clavus, with an oblique sclerotised bar produced into a heavily sclerotised tooth or clasper at its upper margin; cucullus narrow, not separated from sacculus; costal edge strongly sclerotised, with a heavily sclerotised expansion or clasper. Aedeagus with paired dentate processes at level of juxta, manica membranous, vesica with cornutus. Juxta simple. Vinculum slightly produced ventrally into a small bulbous saccus.

Female genitalia: Bursa copulatrix with paired signa; ductus bursae long, broad, widening gradually into bursa, with some heavy sclerotisation; ductus seminalis opening into base of bursa. Ostium strongly transverse, sometimes ovoid, ostial segment sclerotised posterior to and sometimes anterior to ostium.

Busseola fusca (Fuller).

B. fusca and the three new species here to be described are all remarkably similar in general appearance and are easily confused, a confusion rendered worse by the extreme variability of *B. fusca* itself. The variation within this species falls into the following main types—

- a. "Typical" specimens, ochraceous or rufous with the wing pattern well defined, as described by Tams & Bowden (1953).
- b. A form with the forewings almost entirely ochraceous or rufous, with the infuscated basal, discal and terminal areas greatly reduced, with or without the remaining fascia and spots.
- c. A heavily infusate form; this has already been noticed from the Gold Coast. I have also seen similar specimens from Southern Rhodesia. The wing markings in this form are of course largely obscured by the general infuscation.

The rufous-ochraceous form (b) is exceedingly similar to *B. quadrata*, sp. n. and *B. segeta*, sp. n., while the infusate form (c) is very like *B. phaia*, sp. n.;

in fact the latter species was at first thought to be possibly a dark form of *B. fusca*.

Among the material of *B. fusca* from Southern Rhodesia that I have seen are specimens reared from *Pennisetum purpureum* (commonly known as Napier Fodder or Elephant Grass). Two of the new species, *phaia* and *segeta*, also occur in this grass in Central and East Africa, respectively, and *Poconoma serrata* (Hampson), recorded from Uganda, is also known to breed in it. There are thus four species, all extremely alike, that may occur in *Pennisetum purpureum* in East and Central Africa; correct identification is thus a matter of considerable importance, since only *B. fusca* is at present known to cause serious damage to cereals.

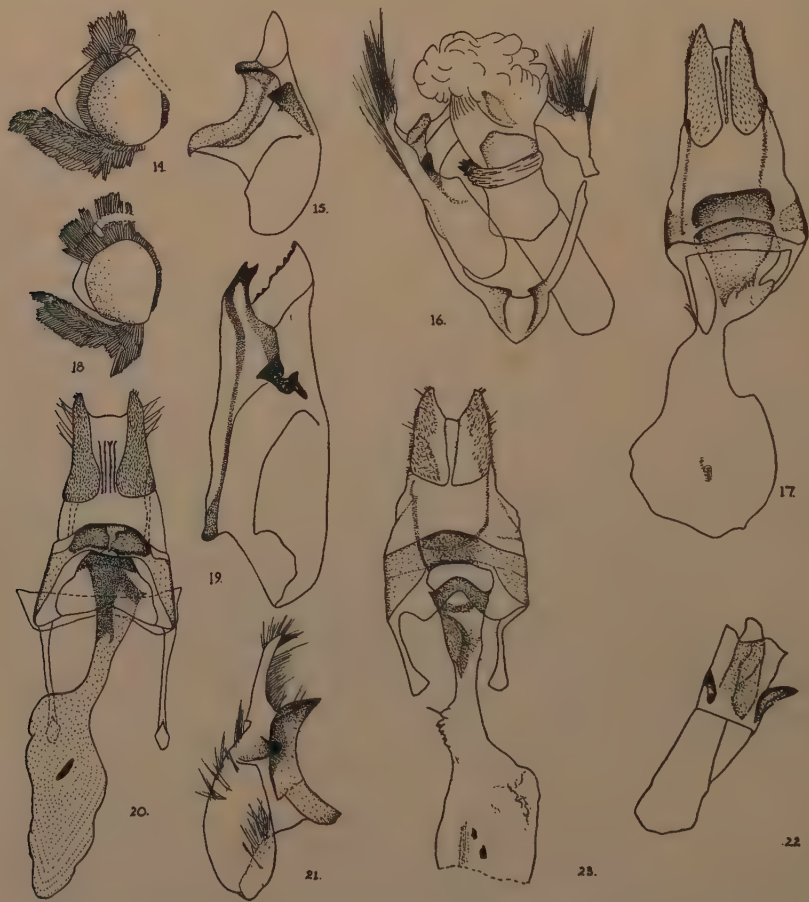
More extensive material from a wide range of localities is required to establish the distributional limits of the various species of the complex associated with *P. purpureum*; with an increasing interest in the problem of stem-borers this material may eventually be forthcoming. Meanwhile the following key will separate those species of *fusca*-like appearance. *B. quadrata*, sp. n., which is very similar to the other four species, is also included, for although at present known only from West Africa, chiefly in *Setaria*, it might well occur in this grass in East Africa.

1. Frons with large blunt prominence *Poconoma serrata* (Hampson)
Frons without prominence, inflated 2
2. Forewing more unicolorous, ochraceous, fuscous or blackish, markings thus less pronounced 3
Forewing more boldly patterned, with infusate areas over a paler ground colour 4
3. Forewing with subterminal fascia consisting of pale spots outlined with fuscous smudges. Hindwing with veins 6 and 7 short-stalked. In male, clasper of valve large and heavily sclerotised. In female, ostial segment with sclerotised plates anterior and posterior to ostium ... *Busseola fusca* (Fuller)
Forewing with subterminal fascia consisting of pale spots not or only vaguely outlined with fuscous. Hindwing with veins 6 and 7 long-stalked. In male, clasper of valve small. In female, ostial segment with sclerotised plate posterior to ostium, anterior lip of ostium thickened ... *Busseola phaia*, sp. n.
4. In male, clasper of valve large and heavily sclerotised. In female, ostium strongly transverse, ostial segment with sclerotised plates anterior and posterior to ostium 5
In male, clasper of valve small, not heavily sclerotised. In female, ostium ovoid, ostial segment lightly sclerotised posterior to ostium
Busseola segeta, sp. n.
5. Forewing with prominent quadrate fuscous fascia between reniform and orbicular spots; without or with weak subterminal pale line or interneural spots. In male, antenna serrate; cucullus of valve with sclerotised serrate edge, aedeagus with small terminal cornutus. In female, ventral lip of ostium indented. (Western species, in *Setaria*) ... *Busseola quadrata*, sp. n.
Forewing without prominent quadrate fuscous fascia between reniform and orbicular spots; with a subterminal fascia of pale interneural spots usually outlined with fuscous. In male, antenna bipectinate; cucullus of valve without sclerotised edge, aedeagus with strong terminal cornutus. In female, ventral lip of ostium not noticeably indented, ostial segment very heavily sclerotised *Busseola fusca* (Fuller)

***Busseola quadrata*, sp. n.**

♂. (Head, fig. 18). Palpus buff, moderately to heavily infusate. Antenna serrate. Head pale cartridge-buff, moderately to heavily infusate and suffused

rufous-brown. Thorax pale buff, moderately to heavily infuscate; tegulae suffused ochreous-brown to rufous-brown at base with a well-defined preapical fuscous band, epaulets heavily infuscate at base. Pectus buff, moderately infuscate and suffused light rufous-brown. Legs pale cartridge-buff, tibiae rather heavily infuscate, tarsi with a white or pale buff apical ring to each segment. Abdomen pale buff or even white, suffused fuscous or fuscous-brown with a fuscous-black to black median patch on dorsum of first segment; anal tuft pale buff with ochreous-fuscous to fuscous suffusion. Forewing buff, with rufous, rufous-brown or rust-



Figs. 14-17.—*Busseola phaia*, sp. n. (14) ♂ head, scales removed from frons; (15) ♂ genitalia, internal view of valve; (16) ♂ genitalia, ventral view; (17) ♀ genitalia, ventral view.

Figs. 18-20.—*Busseola quadrata*, sp. n. (18) ♂ head, scales removed from frons; (19) ♂ genitalia, internal view of valve; (20) ♀ genitalia, ventral view.

Figs. 21-23.—*Busseola segeta*, sp. n. (21) ♂ genitalia, internal view of valve; (22) Aedeagus; (23) ♀ genitalia, ventral view.

brown suffusion at base, extending and becoming paler to postmedian fascia; orbicular and reniform spots conspicuous, white or buff-white, sometimes with a pale fuscous centre, outlined with fuscous-black and connected by a prominent fuscous-black to black quadrate fascia; a curved feebly dentate antemedian fuscous-black fascia; a postmedian fuscous-black fascia, curved outwards to vein 6,

then oblique and feebly dentate towards inner margin; termen with fuscous-brown suffusion, either as an oblique band from termen just below apex to inner margin, or completely suffused from just below apex to inner margin, in which case the wing shows an oblique pale buff band suffused pale fuscous-brown from apex to inner margin and with a weakly defined subterminal series of interneural pale buff spots from between veins 6 and 5 to between veins 2 and 1; a terminal series of interneural fuscous-black spots vaguely connected with fuscous-black; veins 8 to 2 outlined with white from cell; fringe buff with basal and apical fuscous bands, extreme tip white. Hindwing white, variably infusate particularly along veins, costa and termen; a terminal fuscous-black line expanded interneurally; fringe buff, flecked with fuscous at base, white at apex. Underside of forewing white, generally infusate but suffused buff and flecked with fuscous along costa and termen; a fuscous-black discoidal spot and a broad postmedian curved fuscous-black fascia; a terminal series of interneural fuscous-black spots. Underside of hindwing white, heavily flecked with fuscous.

Expanse, 27–34 mm.

Male genitalia (fig. 19): Peniculi rather pointed. Valve with sacculus narrow, the clasper triangular in shape, sometimes with a recurved tip; cucullus pointed, with a narrowly but heavily sclerotised dentate margin; costal margin broadly sclerotised, costal spine well developed, apex bifid. Aedeagus with small paired dentate processes; cornutus of vesica weak. Vinculum shallow, broadly rounded, slightly indented.

♀. Similar to male, but much darker; fascia on wings fuscous-black to black, the orbicular and reniform spots thus more conspicuous, with a marked ochraceous-fuscous or fuscous centre.

Expanse, 33–49 mm.

Female genitalia (fig. 20): Ductus bursae long, heavily sclerotised at ostium and on one side almost to bursa. Ventral lip of ostium broadly indented.

♂ Type: GOLD COAST, Ahinsan nr. Kumasi, bred *ex Setaria chevalieri*, 24. x. 1951. ♀ Allotype: GOLD COAST, Mile 19–20 Kumasi–Mampong Road, bred *ex Setaria chevalieri*, 12. x. 1951. Paratypes: GOLD COAST, ♀, Kumasi, 28. ix. 1952 (bred *ex Pennisetum purpureum*); ♀, Mile 33 Kumasi–Mampong Road, 19. vii. 1951 (bred *ex Zea mays*); ♂, Kumasi, 25. ix. 1950; ♀, Mile 11 Kumasi–Offinso Road, 26. ix. 1951; Kumasi–Mampong Road, Mile 19–20, ♂, 7 and 11. x. 1951; Mile 30–31, ♀, 9. x. 1952, ♂, 2, 10, 14 and 16. x. 1952; Mile 33, ♂, ♀, 6. x. 1951 (all bred *ex Setaria chevalieri*).

B. quadrata is at once separated from *B. fusca* by the distinctive quadrate fascia between the orbicular and reniform spots and, in the male, by the weaker development of the clasper and costal spine; in the female by the less heavily sclerotised ostial segment.

B. quadrata is a high-forest species; it overlaps *B. fusca* in a transitional zone of dry deciduous forest, but in the southern moist deciduous forest it appears to replace *fusca* entirely. The larva is easily recognised, being adorned with bright purple stripes.

Busseola phaia, sp. n.

♂. (Head, fig. 14.) Palpus fuscous, flecked with pale buff. Antenna short-bipectinate, setose, shaft pale buff. Head fuscous to fuscous-black mixed with white, particularly at vertex, which is sometimes pale ochraceous. Thorax fuscous to fuscous-black, the scales, especially on tegulae, pale tipped, epaulets sometimes with purplish reflections. Pectus fuscous. Legs fuscous to fuscous-black, with long fringing hairs paler, tarsi with pale rings at tip of each segment. Abdomen fuscous or ochreous suffused fuscous, anal tuft more heavily infusate. Forewing ochreous suffused fuscous at base and on disc, termen more heavily suffused fuscous-black; an area along costa to apex and then obliquely to inner margin

suffused pale fuscous; orbicular spot pale with fuscous centre; reniform spot large, pale with fuscous centre; three or four very small subapical white or ochraceous-white spots on costa, the last merging into a small ochraceous-white apical patch; a curved, slightly waved and indistinct fuscous-black antemedian fascia; postmedian fascia fuscous-black, curved outwards from costa, oblique and slightly dentate from vein 8 to inner margin; an oblique subterminal row of small pale interneural spots along the inner margin of the terminal infuscated area; a terminal series of black interneural spots, sometimes only a vaguely interrupted fuscous line; veins 3 to 7 and lower margin of cell lightly outlined with white; fringe ochraceous, heavily infusate. Hindwing light ochreous, suffused and flecked with fuscous, particularly on outer margin, with sometimes a faint curved fuscous-black discal fascia; fringe very pale ochreous lightly flecked with fuscous. Underside of forewing generally suffused fuscous except a broad area along inner margin which is entirely pale buff or pale ochreous; costa with three or four subapical ochraceous spots, the last merging into an apical ochraceous patch; a fuscous-black patch at apex of cell and a terminal series of fuscous-black interneural spots; fringe ochreous suffused fuscous.

Expanse, 29–32 mm.

Male genitalia (figs. 15, 16): Valve broad; clasper short but heavily sclerotised; costal margin broadly and heavily sclerotised, costal process large and rather blunt. Aedeagus with dentate processes large, vesica of cornutus only a lightly sclerotised basal patch.

♀. Similar to male but larger. Forewing sometimes less heavily suffused fuscous, the wing markings more prominent.

Expanse, 32–38 mm.

Female genitalia (fig. 17): Dorsal signum of bursa rather faint; sclerotised area of ductus bursae extending well down from ostium, ending obliquely. Ventral lip of ostium thickened, ostial segment sclerotised posteriorly to ostium.

♂ Type: SOUTHERN RHODESIA, Henderson, bred *ex Pennisetum purpureum*, 23. xi. 1953 (D. J. W. Rose). ♀ Allotype: SOUTHERN RHODESIA, Henderson, bred *ex Pennisetum purpureum*, 20. xi. 1953 (D. J. W. Rose). Paratypes: SOUTHERN RHODESIA, Henderson, 4♂♂, 7♀♀, all bred *ex Pennisetum purpureum*, 11–23. xi. 1953 (D. J. W. Rose).

The material from which this species is described is part of that referred to by Whellan (in discussion, Bowden, 1954), as reared from *Pennisetum purpureum* and identified as *B. fusca*. I have already noted that some of the specimens sent to me are undoubtedly *fusca*, so that in Southern Rhodesia we now know two species of *Busseola* existing in the same host-plant in the same locality.

B. phaia is most easily distinguished from *fusca* by the genitalia. In the male the clasper is small though heavily sclerotised and the costal expansion is more ridge-like, not produced into a large spine as in *fusca*. Although these differences appear considerable (compare figs. 8–10 in Tams & Bowden, 1953), they are differences of degree only; *B. quadrata* provides an intermediate stage of development. The female genitalia are much more like *fusca*, the main difference being that in *phaia* the ostial segment has only one sclerotised plate, that posterior to the ostium.

Busseola segeta, sp. n.

♂. Palpus pale, flecked with fuscous. Antenna short-bipectinate, shaft buff with pale and fuscous scales. Head pale, flecked with fuscous particularly on vertex. Thorax pale, infusate, especially on tegulae and epaulets, the infuscation on the tegulae more sharply defined into median and subterminal fuscous-black bands. Pectus infusate. Legs pale, infusate, especially forelegs, tarsi with a pale ring at apex of each segment. Abdomen infusate. Forewing light ochreous, suffused with fuscous at base, over cell and broadly along termen;

orbicular and reniform spots pale, rather indistinct and defined by fuscous-black; a slightly curved feebly dentate antemedian fuscous-black fascia; a postmedian fuscous-black fascia curved towards termen to vein 6, then dentate and oblique to inner margin; an oblique subterminal fascia of pale interneural spots from apex to inner margin, defined proximally by wedge-shaped fuscous-black marks and distally by smaller fuscous-black marks; a terminal series of fuscous-black interneural spots; veins outlined with white; fringe generally infusate. Hindwing pale, flecked with fuscous on disc and generally infusate along margin; fringe pale buff, lightly infusate. Underside of forewing pale, suffused and flecked with fuscous; a fuscous discal spot; a terminal series of small interneural fuscous spots; veins outlined with white towards termen; fringe infusate. Underside of hindwing pale, flecked with fuscous, particularly along termen; fringe infusate.

Expanse, 25 mm.

Male genitalia (figs. 21, 22): Peniculi rather blunt. Valve rounded, the sclerotised process small and blunt; cucullus very narrow with a faintly serrated edge; costal margin broadly sclerotised, costal process well developed and sharply pointed. Processes of aedeagus small.

♀. Similar to male, but forewings more boldly patterned, with the infuscation sometimes reduced, the wing thus appearing ochraceous, or strongly intensified almost to black. Hindwing more generally infusate.

Expanse, 27–32 mm.

Female genitalia (fig. 23): Bursa copulatrix with signa rather weak; ductus bursae fairly heavily sclerotised from ostium for about half its length. Ostium shortened transversely and widened longitudinally, its anterior lip convex strongly produced into ostium; ostial segment only lightly sclerotised posterior to ostium.

♂ Type: UGANDA, Serere Exp. Station, bred *ex Sorghum verticilliflorum*, 20. v. 1955 (W. R. Ingram). ♀ Allotype: UGANDA, Serere, Kikota, bred *ex Pennisetum purpureum*, 24. iii. 1955 (W. R. Ingram). Paratypes: UGANDA, ♀, Serere Exp. Station, bred *ex Panicum maximum*, 4. iv. 1955; ♀, Serere, Kiwuliriza, bred *ex Pennisetum purpureum*, 11. iv. 1955 (both W. R. Ingram).

This species was first recognised as distinct by its collector, Mr. W. R. Ingram, and confirmed as such by Dr. I. W. B. Nye. In wing colour and pattern it resembles both *B. quadrata* and some specimens of *B. fusca* of form (b) described earlier; from both of these it is easily separated by the genitalia, which show it to be very close to *B. phaia*. The male genitalia are sufficiently alike to suggest that *phaia* and *segeta* are no more than subspecies; the female genitalia are markedly different, however, the ovoid ostium of *segeta* being unlike that of any of the other species of *Busseola* dealt with here. This, together with its different general appearance and geographic separation, is considered sufficient to justify specific rank.

The four adults of the type series were reared from larvae in host-plants belonging to three quite different genera; one may thus infer that within its ecological limits it will be markedly polyphagous. This possibility, combined with its very close resemblance to *B. fusca*, suggests that *segeta* has in the past been misidentified as *fusca*, and also that investigation may reveal it as a widespread and possibly damaging species.

Summary.

Six new species of stem-boring AGROTIDAE are described from Africa. The new genera, *Carelis*, *Poccopa* and *Manga* are erected to accommodate three of these species; the other three species are described in the genus *Busseola*.

A key to nine genera is given, and also one to separate five extremely similar species, *Poconoma serrata* (Hampson), *B. fusca* (Fuller), *B. quadrata*, sp. n., *B. phaia*, sp. n., and *B. segeta*, sp. n.

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I am grateful for the opportunity of studying the interesting material made available to me by Messrs. J. A. Whellan and D. J. W. Rose of the Department of Agriculture, Southern Rhodesia, and also that sent by Mr. W. R. Ingram, of the Department of Agriculture, Uganda, for examination at the Commonwealth Institute of Entomology. Mr. W. H. T. Tams has given me the benefit of his advice, and I have had useful discussions with Dr. I. W. B. Nye and Mr. E. O. Pearson. The paper is published by permission of the Director of Agriculture, Gold Coast.

References.

- BOWDEN, J. (1954). The Stem-borer problem in tropical cereal crops.—Rep. 6th Commonw. ent. Conf. 1954, pp. 104–110.
- TAMS, W. H. T. & BOWDEN, J. (1953). A revision of the African species of *Sesamia* Guenée and related genera (Agrotidae–Lepidoptera).—Bull. ent. Res., **43**, pp. 645–678.
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A NEW GENUS AND SPECIES OF MIRIDAE FROM
 ARECA CATECHU IN SOUTH INDIA
 (HEMIPTERA HETEROPTERA).

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The following description is based on material submitted for identification to the Commonwealth Institute of Entomology by the Government Entomologist, Coimbatore, S. India. The specimens were immediately recognisable as a new genus of the well-defined Mirid subfamily BRYOCORINAE tribe Odoniellini of which only 18 genera are known. Of these no less than 15 genera are represented in the British Museum (Nat. Hist.).

Carvalhoia, gen. nov.*

Head transverse with eyes prominent and almost pedunculate; vertex lightly convex with a short obscure linear furrow in middle of base, anteriorly rounded without prominences or tubercles of any kind; antennae extending to apex of clavus, the second and third segments with tuberculate swellings bearing erect bristles, widened to apex, the fourth fusiform; rostrum short extending to midway between anterior and intermediate coxae. Pronotum (excluding collar and calli) and scutellum, distinctly, regularly punctate, the whole covered with long, fine, erect hairs. Scutellum a little shorter than wide at base, triangular, the apex sub-acute, strongly convex but not inflated. Hemelytra smooth and shining without punctures, rugosities or shagreening, covered with erect pubescence distinctly shorter than on pronotum; cuneus relatively small, longer than broad at base. Abdominal connexiva widely visible beyond costal margins of elytra. Legs relatively slender, the anterior and intermediate femora subequal to tibiae, the posterior femora a little shorter than tibiae.

Type species: *Carvalhoia arecae*, sp. nov. (fig. 1).

Closely allied to *Platyngomiris* Kirkaldy (Malaya), *Pseudodoniella* China & Carvalho and *Volkelius* Distant (Australia). Differs from *Platyngomiris* and *Pseudodoniella* in the short non-vesicular scutellum and in the tuberculate second and third antennal segments; from *Pseudodoniella* in the absence of the anterior process of vertex between the basal antennal joints and in the sub-pedunculate eyes and from *Volkelius* in the absence of rugosity on pronotum and scutellum, more pedunculate eyes, long erect pubescence especially on pronotum, smooth shining non-crinkled hemelytra and in the tuberculate second and third antennal segments. *Carvalhoia* differs from the Tibetan *Rhopaliceschatus* Reuter in the absence of the paired tubercles at anterior margin of vertex and in the non-vesicular scutellum. It also differs from *Volkeliopsis* in the absence of the paired tubercles on anterior margin of head.

* Dedicated to Dr. José C. M. Carvalho in recognition of his outstanding work on the classification of the MIRIDAE.

Key to Genera of ODONIELLINI allied to *Volkelius* Distant.

1. Head with two tubercles or a strong prominence on anterior margin between antennae 2
- Head without such process, only slightly rounded in front 4
2. Scutellum vesicular 3
- Scutellum convex but not vesiculate, transversely impressed at base. Philippines *Volkelioipsis* Poppius
3. Clypeus visible from above between the two apical tubercles of vertex. Scutellum hemispherical. Tibet *Rhopaliceschatus* Reuter
- Clypeus not visible from above, but hidden by the median prominence of vertex. Scutellum heart shaped with apex indented. New Britain *Pseudodoniella* China & Carvalho
4. Scutellum vesicular. Malaya *Platyngomiris* Kirkaldy
- Scutellum not vesicular 5
5. Pronotum and scutellum rugosely punctate; hemelytra crinkled in places. Australia *Volkelius* Distant
- Pronotum and scutellum not rugose but distinctly, regularly punctate; hemelytra smooth without crinkles. S. India *Carvalhoia*, **gen. nov.**

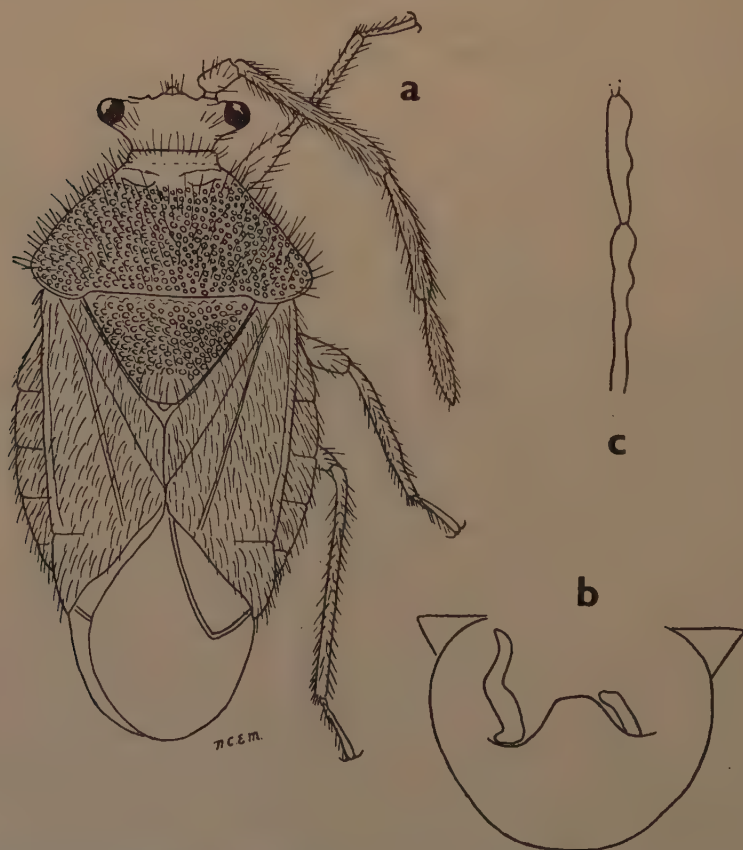


Fig. 1.—*Carvalhoia arecae*, gen. et sp. nov. a, dorsal view of whole insect; b, terminal view of genital segment to show parameres; c, segments 2 & 3 of antennae, lateral view.

Carvalhoia arecae, sp. nov.

Colour: ♂ and ♀ bright orange fulvous, the eyes, antennae (except basal segment) scutellum, margin of clavus close to scutellum and along claval commissure, dark brown; extreme apex of corium, cuneus, membrane all black. Pubescence black, underside and legs pale orange, the apex of abdomen and genital segments black. Tibiae tinted with red, ventral abdominal pubescence pale. Posterior margin of pronotum in front of scutellum infuscate.

Structure: ♂ (24 = 1 mm.). Head more than two-and-a-half times wider across eyes than long in middle (34:13), and four times wider between eyes than width of one eye (22:5.5); relative length of antennal segments 9:41:28:25. Pronotum twice as wide at base as long in middle including collar (60:30). Scutellum wider at base than long in middle (34:24), the claval commissure equal in length to scutellum. Cuneus longer than broad at base (16:10). Parameres figured (fig. 1, b).

Total length: ♂ 5.8 mm., ♀ 6.0 mm. Breadth across humeral angles, ♂ 2.5 mm., ♀ 2.54 mm.

Habitat: S. India, S. Kanara District, 1 ♂ (type) and 3 ♀ paratypes. March 1955, on leaves of *Areca catechu*. Type in British Museum (Natural History), London.

TRIALS OF RESIDUAL INSECTICIDES IN WINDOW-TRAP HUTS AGAINST MALAYAN MOSQUITOS.*

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Introduction.

This paper summarises a long series of trials, made during the five years 1949 to 1953, in which DDT, BHC and dieldrin were tested in window-trap huts against different species of mosquitos. Some of the results with DDT and BHC, but not those with dieldrin, have already been published (Wharton & Reid, 1950; Wharton, 1951a, 1951b; Reid, 1951b).

The origin of these trials was as follows. In 1948, with the aid of Colonial Development and Welfare funds, an experiment had been started on the control of rural malaria with residual insecticides (Edeson & others, 1954). During the period of preliminary observations, and before control began, we had to try to decide what doses of insecticide to use and how often to apply them. There did not seem to be any satisfactory way of deciding these points in the laboratory; one attempt by Reid (1951a) was only partially successful. Only field methods could tell us what happened to wild mosquitos entering houses sprayed with residual insecticides. The vector of malaria in the areas chosen for the experiment was *Anopheles maculatus* Theo., the principal vector in Malaya which, like most Malayan mosquitos, does not rest indoors by day. Thus no method based on searching houses by day was likely to be of much use. Some dead mosquitos killed by the insecticide might possibly be found, but Muirhead Thomson's important work (1947) had shown that whether mosquitos subsequently died or not they were irritated and escaped from a DDT-sprayed house, and any found inside would probably be only a small fraction of those which had entered during the night. It was essential to catch these escaping mosquitos to obtain an adequate picture of the effect of insecticides, and it was therefore decided to try Muirhead Thomson's technique of the "window-trap hut".

* Aided by a research grant received from Colonial Development and Welfare funds, through the Colonial Insecticides, Fungicides and Herbicides Committee, and the Colonial Medical Research Committee.

Areas and Methods.

Areas.

Attention was concentrated at first upon *A. maculatus*, in connection with the rural malaria control experiment mentioned in the introduction. For the purpose of this experiment a branch laboratory had been established at Tampin, some 75 miles south of Kuala Lumpur, and a suitable site for window-trap huts was found on a nearby rubber estate (for details see Wharton, 1951b). Several species of *Anopheles* and other mosquitos were common on this estate, but only *A. maculatus* and *Culex pipiens fatigans* Wied. were regularly taken in the window-trap huts when these were baited with men. At the time the experiments with window-trap huts were commenced in 1949, no DDT or other residual insecticides had been used in the area. The following year there was some token DDT-spraying of the labourers' lines, but this does not appear to have affected our trials in any way.

In 1950 the work was extended to include other vectors of malaria besides *A. maculatus*, and during the next two years window-trap huts were erected at several places within reach of Kuala Lumpur, at one or other of which *Anopheles sundaicus* (Rdnw.), *A. barbirostris* Wulp, *A. letifer* Sandosham and *A. umbrosus* (Theo.) occurred. Many other mosquitos were present, and in addition to these Anophelines a few species of *Culex*, *Mansonia* and *Aedes* entered the huts in significant numbers. For notes on the species which entered the huts, see the next section, "species studied". The places chosen were in Malay rural areas (kampongs) near the coast, and no residual insecticides were used in these areas. Some four years before, small experiments with outdoor barrier spraying of DDT had been made by Nair (1949a, 1949b) in two areas nearby, but these only lasted a few months and do not appear to have included the sites selected for the window-trap huts. House spraying did not begin to come into use as a public health measure in Malaya until late 1951 (Anderson, 1954), and at the time of writing it has not yet been used in the kampongs where the window-trap huts were operated; nor have DDT or similar substances been used as larvicides in these areas.

Species studied.

Although ten species or groups of species (see Table V) were caught in the window-trap huts in numbers sufficient to be worth recording, this paper is mainly concerned with only three of them. This is because the figures for these three (*Anopheles maculatus*, *A. sundaicus* and *C. pipiens fatigans*) are much more complete than for the others, and in the main the conclusions for these three apply also to the other species. There follow here some brief notes on all the species. Additional general information about the vectors of malaria and filariasis in Malaya can be found in Field & Reid (1951) and Wilson & Reid (1951).

Anopheles maculatus Theo. is the principal malaria vector in Malaya, especially inland, and occurs in all cultivated hilly areas from the coast to about 5,000 ft. in the mountains. Adults enter houses at night to bite, but feed more readily in the open and prefer cattle to humans; they rest strictly outdoors by day. For more information on the biology of the adults see Wharton (1951c, 1953a, 1953b).

A. sundaicus (Rdnw.) breeds in brackish water and is an important malaria vector along the coast. The biting and resting habits of the adults are broadly the same as those of *A. maculatus*, and so far as is known the same applies to the next three species.

A. barbirostris Wulp occurs in two forms (Reid, 1947). The form with which this paper is concerned (the "dark-winged") is found mainly on the coastal

plains where it is a vector of malaria, and also of filariasis due to *Wuchereria malayi* (Malayan filariasis).

A. letifer Sandosham and *A. umbrosus* (Theo.) are also found mainly on the coastal plains, but they avoid brackish water which *A. barbirostris* can tolerate to a limited extent. Both are malaria vectors, but *A. letifer* is more important as it occurs in cultivated land, and is thus more closely associated with man than *A. umbrosus* which prefers swamp forest. For more information on these species see Reid & Hodgkin (1950).

Culex pipiens fatigans Wied. occurs throughout the tropics, and in Malaya, as elsewhere, it is particularly common in urban areas, resting in houses by day, biting humans at night, and breeding in dirty water around houses. It is a hardy mosquito difficult to control except by good drainage and sanitation. Apart from *Aedes aegypti* (L.), it is about the only mosquito in Malaya which normally rests indoors by day (Reid, 1954). It is a potential vector of filariasis due to *W. bancrofti* (Bancroftian filariasis).

The *Culex* spp. in Table V were *C. gelidus* Theo., *C. vishnui* Theo. and *C. sitiens* Wied. The first two are common everywhere in settled and inhabited areas, but *C. sitiens* is confined to the coast where it breeds in brackish water. All three prefer the blood of cattle to that of humans, and bite chiefly outdoors. The American Army Research Unit, working at this Institute, has isolated the virus of Japanese B encephalitis from *Culex gelidus* (F. R. McCrumb, personal communication).

The species of *Mansonia*, subgenus *Mansonioides*, are the principal vectors of Malayan filariasis, especially in the most heavily infected areas. They are strong fliers and fierce biters, apparently without any pronounced blood preferences. They bite readily by day in the shade, and may occur in enormous numbers at night in the heavily infected areas. In such places the dominant species is *M. longipalpis* (Wulp) (together with the very similar *M. bonneae* Edw.). *M. longipalpis* and *M. uniformis* (Theo.) are probably the most important species, and they formed a large proportion of the *Mansonia* caught in the window-trap huts.

Aedes albopictus (Skuse) is a very common pest mosquito biting principally by day, but also to some extent at night. It is a vector of dengue and is common around houses, though unlike *Aë. aegypti*, it breeds, bites, and rests mainly outdoors. It is also common far away from houses, even in clearings in the forest, and is often very troublesome on rubber and coconut estates where it breeds in latex cups and fallen coconuts. *Aë. butleri* Theo. inhabits the landward fringe of the mangrove swamps and breeds in ground pools and crab-holes. By day it bites freely in the shade near its breeding places, but is more active at night and will then enter houses.

Methods.

The structure and operation of the window-trap huts have been described and illustrated by Wharton (1951b); only the essentials will be repeated here.

(i) *Structure of the huts*.—The huts were built of wood and palm thatch, raised a foot or two off the ground, thus resembling a small Malay house. The floors were of wooden planks, whilst the walls were lined inside with an opaque brown packing paper (sisalkraft) which also formed the ceiling. This paper made a cheap and easily replaceable lining for the huts, upon which wettable powders behaved in much the same way as on the unpainted wood, split bamboo or palm thatch which form the walls of rural houses in Malaya. By using this paper, a smooth-walled closed room was formed about 8 ft. long, 5 ft. wide, and 6 ft. high, in which mosquitos could easily be found. The only openings were the door, the louvres, and the window. The door was guarded on the inside by overlapping curtains of black cloth to exclude light, and to prevent

mosquitos escaping when anyone entered or left the hut. The louvres were the only means of entry for mosquitos; they were of the ordinary type used for ventilation in tropical houses, and consisted of a pair of vertical panels placed opposite one another in the long sides of the hut, and occupying about one third of the area of each side. Each louver panel, about $2\frac{1}{2}$ ft. wide by $5\frac{1}{2}$ ft. high, was formed by a series of transverse wooden slats painted black, set one above the other about $1\frac{1}{2}$ in. apart, and sloping downwards and outwards like the slats of a fixed venetian blind. Through the openings in these louvres the scent of the bait could escape (a most important point), and mosquitos could enter, and also escape to some extent (p. 438). Several types of baffle slit entrance were tried to prevent mosquitos escaping, but these also prevented them from entering, and the simple louvres were found to be the best compromise. Mere adventitious cracks which were sufficient to allow *Anopheles gambiae* Giles and *A. funestus* Giles to enter Muirhead Thomson's huts, were totally inadequate for *A. maculatus*, which is an outdoor mosquito much less addicted to human blood, and fairly easily discouraged from entering houses (Wharton, 1951c). Owing to the downward slope of the black-painted slats, very little light entered through the louvres; when mosquitos left the hut the majority were attracted to the dim light coming in through the single window, one foot square, in the end of the hut furthest from the door. Over the outside of this window was fixed a detachable window trap, which was simply a gauze cage on a wooden frame with a funnel entrance, and a sleeve through which to take out mosquitos.

(ii) *Operation of the huts.*—The method of operating the huts was as follows. A member of our staff (collector), stationed on the spot, was in charge. At about 7 p.m. local time (sunset varies between approximately 6.30 and 7 p.m.) on five nights a week, he laid a white sheet on the wooden floor of the hut, placed the window trap in position, and shut in one or two men or boys hired to sleep in the hut. He operated a net trap nearby with himself as bait until 11 p.m., and rose at 5 a.m. to make a final catch in the net trap before attending to the hut. The catch in the net trap was a useful indication of the mosquitos present in the area and their seasonal fluctuations, and gave a standard with which to compare the more limited catch in the hut. Entering the hut shortly after 5 a.m., the collector covered the inside of the louvres to prevent mosquitos escaping except into the window trap, and released the sleepers. At about 8 a.m. or earlier (sunrise approx. 6.30–7 a.m.) he searched the hut carefully for living or dead mosquitos, and removed the window trap. The mosquitos were sent back to the laboratory for identification, and were recorded as alive or dead, blood-fed or unfed, and whether found in the hut or window trap. Living specimens were kept in lamp-chimneys in an insectarium, and deaths were recorded at 8 and 24, and sometimes 48, hours after capture.

At Tampin there were three, and later four huts, and during the first two seasons, 1949 and 1950, one hut was kept untreated as a control. Elsewhere there was usually only one hut at each site, and a pretreatment period served as control. To perform an experiment, a favourable site and season had to be selected, so that there would be sufficient numbers of the vector mosquito; this was often a serious difficulty.

All the experiments recorded here were made with wettable powders. Three formulations of DDT were used; in 1949, a powder containing 33 per cent. of DDT (Stafford Allen); in 1950, one containing 25 per cent. (Imperial Chemical Industries); and from 1951 onwards, one containing 50 per cent. DDT (Imperial Chemical Industries). The BHC used was a 50 per cent. powder (Imperial Chemical Industries, P520), with a γ -isomer content of 6.5 per cent. The dieldrin was a 25 per cent. powder (Shell).

Except for a few trials with light doses (p. 453), relatively heavy doses were used—200 mg. of DDT per sq. ft., 40 of γ BHC, and 40 of dieldrin. These doses

were chosen following the first trial with window-trap huts, when DDT at 100 mg. and γ BHC at 20 mg. apparently ceased to kill *A. maculatus* after about eight weeks or less (Wharton, 1951b). This trial was eventually discounted, and the later trials with light doses gave rather better results, but in the meantime the heavy doses had proved to be necessary if the insecticides were to last six months against *A. maculatus*.

After measuring the area to be treated inside a hut, the required amount of insecticide was weighed out and applied in water with a paint brush to the paper walls and ceiling. In this way the correct dose was put on as an evenly distributed deposit. Care was taken not to get insecticide on the louvres or the window opening, but the door curtains were treated. Before commencing a new experiment, the old paper lining of the hut was replaced with fresh paper. Precautions were necessary against ants, lizards, cockroaches and spiders, which were liable to eat both living and dead mosquitos. The huts were frequently searched for these pests by the collector, and from time to time sticky bands were applied to the legs of the hut. As a check on these precautions a known number of dead mosquitos, lightly gummed to bits of paper, was exposed on the floor of the hut about once a week. The disappearance overnight of any of these dead mosquitos was the signal for further measures.

(iii) *Presentation of results.*—Numerous trials were made, especially with *A. maculatus*. For example, there were five trials, one per annum, of DDT at 200 mg. per sq. ft. against *A. maculatus*. This was partly because the full duration of this dose could not be determined in one season, as the numbers of *A. maculatus* do not remain high for long enough (Wharton, 1951a), and partly because this dose was used as a standard with which to compare other doses and insecticides. This repetition has produced an enormous mass of figures, and in order to present the results at all, it has been necessary to compress and simplify as much as possible. All such replicates have been added together and the figures are presented here as if they were from a single experiment performed in one year. This may not be ideal, but there has been quite good agreement between the replicates, especially for the 24-hour kills. These summarised figures form a series of Tables (VIII–XVI) which are placed in an Appendix at the end of this paper, and all Tables and graphs in the text can be derived from them.

Though the main purpose was to measure kills due to the insecticides so as to define suitable doses for practical use, we were also interested in the effects of the insecticides on the biting and resting behaviour of mosquitos. As this behaviour necessarily precedes kills and may influence them, it has seemed more logical in this paper to discuss behaviour first. By doing this we have sometimes had to anticipate conclusions belonging to a later section of the paper, e.g., about toxicity or speed of action, but this cannot very well be avoided.

Validity of the Window-trap Hut Technique.

The object of the technique is to obtain a reliable guide to the death-rate among mosquitos entering dwellings sprayed with residual insecticides. The use of actual dwellings or occupied rooms would seem to be the ideal procedure, but is rarely satisfactory in practice. Existing dwellings are not usually sited in the best position to attract the maximum number of vector mosquitos, and there are usually too few or too many openings. Irregularities of the walls and the presence of clothes, furnishings, a high roof, etc., make it very difficult to search rooms effectively. Finally, the occupants must be subjected to a rigid routine from sunset to dawn which is irksome to them. The use of huts specially built for the purpose is the best solution to this difficulty, even though one cannot be quite certain that the kills recorded in these huts are exactly the same as will occur in treated dwellings. Two likely sources of error must be discussed.

Number of mosquitos found in relation to number entering.

If the mosquitos found in the hut and window trap in the morning were only a small proportion of those which had entered during the night, one would not be justified in assuming that the death-rate in this proportion gave a true estimate of the total death-rate. Wharton (1951b) investigated this point by placing exit traps over a portion of the louveres, and found that although considerable numbers of mosquitos do escape through the louveres, the majority will be found in the hut and window trap, especially if the hut has been treated with insecticide. In an untreated hut he estimated that 56 per cent. of *A. maculatus* which entered were recovered, and 44 per cent. escaped by way of the louveres. But in a hut treated with DDT at 200 mg. per sq. ft. only 21 per cent. escaped through the louveres during the first 16 weeks after treatment, and with γ BHC at 40 mg. per sq. ft. the figure was only 16 per cent. Further, the death-rate among those caught in the exit traps over the louveres was the same as among those caught in the window trap. Thus the estimated death-rate for the total number of *A. maculatus* believed to have entered (that is the number recovered plus the number estimated to have escaped through the louveres) was the same as for those actually recovered. The smaller proportion escaping through the louveres from treated huts may be due to enhanced attraction to light (the window) following activation by insecticides, at least by DDT (Kennedy, 1947; Downs & Bordas, 1951); also, while the insecticide is fresh, considerable numbers are killed inside the hut before they can leave.

Proportion of surface treated in window-trap huts and in houses.

In the window-trap huts nearly every surface was treated with insecticide; only the louveres, the window frame, and the floor with men sleeping on it, remained untreated. In the average rural house in Malaya there is no ceiling and the inside of the roof is too high to be easily sprayed; also there are articles of clothing and other things which are not sprayed. This would lead one to expect a smaller kill in houses than in window-trap huts, and this may in fact occur. But there is reason to think that the difference, if any, is not great. An experiment in the window-trap huts 10-13 weeks after treatment suggested that within limits the kill is not affected by reduction in the treated surfaces. On alternate nights one quarter of the treated surface was covered by hanging untreated brown paper on the walls, and the death-rate of *A. maculatus* on these nights was compared with the rate when the whole treated surface was exposed. The results are shown in Table I.

TABLE I.

Comparing death-rates of *A. maculatus* over a four-week period in huts with all internal surfaces treated, or one quarter untreated. Insecticide deposits 10-13 weeks old.

Insecticide and dose per sq. ft.	All surfaces treated			One quarter untreated		
	Total caught	% found dead	% dead after 24 hr.	Total caught	% found dead	% dead after 24 hr.
DDT—200 mg.	105	30	72	262	37	71
γ BHC—40 mg.	65	9	63	49	6	69

Clearly there is no difference in the kills. Presumably mosquitos rest in several places before escaping into the window trap, so that provided the untreated surface does not exceed the treated surface in area they will usually

make contact with the insecticide at some time. There is the possibility that the kill from particulate and fumigant action of DDT and BHC was sufficient to mask any effect due to covering one quarter of the treated surface. However, this seems unlikely, for Davidson (1953) found only slight evidence of particulate action from DDT deposits 10–13 weeks old, and DDT has no fumigant effect.

In contrast to this result, there are a number of reports showing that partial treatment often does reduce the kill. Tarzwell & Stierli (1945) found that mortality among *Anopheles quadrimaculatus* Say escaping from DDT-sprayed rooms was much lower if the rooms were occupied and contained unsprayed furnishings than if unoccupied. Davidson found that spraying the roof only of a window-trap hut gave low kills of *A. gambiae* and *A. funestus*, though these species had been observed to rest by day, mainly in the roof, in an untreated hut. The explanation would seem to be that the effects of partial spraying depend upon the resting habits of the mosquito in relation to the particular surfaces left unsprayed. The available evidence is that, after feeding, *A. maculatus* normally rests on the walls not far above the floor (Wallace, 1948; J. A. Reid, unpublished). Those few Anophelines (they do not include *A. maculatus*) which can be found indoors by day in Malaya are mostly found on the walls rather than on furnishings. In unsprayed Malay houses, 73 per cent. were found on the walls and only 27 per cent. on mosquito nets, furniture, etc. In BHC-sprayed houses more than half were still found on the sprayed walls. With the non-irritant dieldrin the proportions would probably be much the same as in unsprayed houses. In both sprayed and unsprayed houses, whether the mosquitos were resting on walls or on furnishings, less than 10 per cent. were found more than six feet above the floor (Edeson & others, 1954). Thus in Malaya to leave the roof and other surfaces above ten feet and some of the furnishings unsprayed should not greatly reduce the kill, and probably does not constitute an important difference between treated window-trap huts and treated houses. *A. quadrimaculatus*, in the experiment quoted above, was presumably resting to a considerable extent on the unsprayed furnishings, while *A. gambiae* and *A. funestus* after feeding probably rested on the walls which were untreated; the roof may have been only a day-time resting place.

Conclusions.

It may be that the small size of the huts compared with most rooms favours more contact with the insecticide, but there is no evidence for this. It is concluded that for *A. maculatus*, and most of the other species investigated, the kills occurring in the window-trap huts are probably a fair guide to the kills that can be expected in sprayed houses. *C. p. fatigans* may be an exception; its habit of resting on clothing might result in less frequent contact with insecticide in a house than in a window-trap hut. On the other hand, with *C. p. fatigans* and a non-irritant insecticide like dieldrin, our practice of catching the mosquitos resting in the hut early each morning would tend to give a lower kill than in a house, where many would remain to rest by day on dieldrin-treated surfaces until they absorbed a lethal dose (p. 451).

Effect of Insecticides on Behaviour.

Effect on number of mosquitos entering.

Several investigators have noted a reduction in the number of mosquitos entering huts after treatment (Muirhead Thomson, 1950; Wilkinson, 1951; Downs & Bordas, 1951), and have wondered whether DDT and BHC are repellent. There was a similar reduction in many, though not all, of our trials, and figures which show this are presented in Table II. It will be seen that the reduction lasted only 2–4 weeks.

Various explanations have been offered to account for this reduction which almost certainly is not due to true repellence (action at a distance by a vapour repelling the mosquito without knocking it down or killing it). The insecticides were applied as wettable powders so there is no question of repellence by an oil

TABLE II.

Reduction in number of mosquitos entering window-trap huts after treatment with insecticides. Average number per night of *A. maculatus* and *C. p. fatigans* before and after treatment.

Insecticide and dose per sq. ft.	<i>A. maculatus</i>					<i>C. p. fatigans</i>				
	Before treat- ment	Weeks after treatment				Before treat- ment	Weeks after treatment			
		1	2	3	4		1	2	3	4
DDT—200 mg.	14.9	8.4	5.9	9.0	15.0	65.4	37.2	19.8	62.1	56.2
γ BHC—40 mg.	11.0	5.3	3.7	5.3	11.8	54.9	17.4	20.6	47.6	85.1
Dieldrin—40 mg.	3.0	0.3	2.0	1.4	4.4	36.0	28.6	64.0	30.4	36.8

solvent, and Hadaway & Barlow (1952) and also Davidson (1953) have shown that the insecticides are not repellent in the strict sense defined above. The former authors showed that mosquitos confined over, but not touching, deposits of volatile insecticides like BHC and aldrin, which have a pronounced fumigant effect, did not move away until the onset of symptoms that led very soon after to knockdown.

Fumigant action is not a likely cause, because in our figures the reduction is much the same with DDT, which has no fumigant effect, as with BHC, which has. Also, fumigant action, at least in the laboratory, is quite slow and may not affect the movements of mosquitos in less than about 20 or 30 minutes' exposure (Hadaway & Barlow, 1952, 1953).

The possibility that there is actually no reduction in the number of mosquitos entering, but an increase in the number escaping back through the louvres is ruled out by the evidence already given (p. 438) which shows that just the reverse occurs; the number escaping through the louvres is much reduced after treatment. Wilkinson (1951) also rejects this explanation, but suggests another which may be true; that the smell of the fresh insecticide deposit masks the odour of the bait inside the hut. There is, however, another possible factor which seems likely to be the main cause of the reduction; this is the particulate effect demonstrated by Davidson (1953). He showed that if mosquitos are confined in a cage hung up inside a treated hut, and not in contact with any of the treated surfaces, there may still be a high kill, especially while the insecticide deposits are fresh. He attributed this to small air-borne particles of the insecticides which had become detached from the walls. In our window-trap huts there is often an appreciable current of air moving through the huts by way of the louvres, and this current would carry such air-borne particles of insecticide; these might affect any mosquitos resting on the outside of the louvres or elsewhere nearby and prevent them from entering.

We may conclude that the insecticides do tend to reduce the number of mosquitos entering treated huts, probably largely by the action of air-borne particles, but that in our experience the effect is usually short-lived and not

TABLE III.

Effect on biting rate of mosquitos of deposits of 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft. Percentages of total found which were blood-fed.

Species	Insecticide	Before treatment	Weeks after treatment							
			1-4	5-8	9-12	13-16	17-20	21-24	25-28	
<i>A. maculatus</i>	DDT	91	82	81	79	74	74	85	89	
	BHC	92	45	55	89	87	90	89	100	
	Dieldrin	97	86	95	92	86	84	90	94	
	Control	87	90	91	83	89	91	97	97	
	Mean	92								
<i>A. sundaiensis</i>	DDT	72	75	80	77	63	—	—	—	
	BHC	93	77	77	76	—	—	—	—	
	Dieldrin	79	86	92	90	93	91	—	—	
	Mean	86								
<i>C. p. fatigans</i>	DDT	74	30	40	46	40	52	53	52	
	BHC	71	31	34	43	64	71	77	78	
	Dieldrin	81	44	61	75	70	78	(65)*	(67)*	
	Control	84	82	83	78	70	66	76	84	
	Mean	75								

* Based on small figures and not included in the graph (fig. 1).

important, and may be quite masked by any large increase in the mosquito population.

Effect of insecticides on biting rate.

A marked difference between *A. maculatus* and *C. p. fatigans* is shown in Table III. Before treatment the average percentage of *A. maculatus* which were blood-fed when recovered from the huts in the morning (referred to as the pre-treatment biting rate) was 92 per cent. In the first month after treatment with DDT the rate was 82 per cent., a reduction of only 11 per cent. in the pre-treatment rate. With *C. p. fatigans* the pre-treatment and post-treatment rates were 75 and 30 per cent., which is a reduction of 60 per cent. in the pre-treatment rate. For the most part this striking difference applies also to later months and other insecticides, and is clearly a regular phenomenon. The obvious explanation is to suppose that *A. maculatus* seldom rests on the wall before biting (and Wallace, 1950, produced some evidence which supports this), but that *C. p. fatigans* frequently does. Consequently, many *C. p. fatigans*, and few *A. maculatus*, would be irritated by contact with DDT and prevented from biting. Whatever the true explanation, *A. maculatus* probably spends less time than *C. p. fatigans* between entry and biting, and it could even be that *A. maculatus* does touch the wall, but bites so soon afterwards that DDT has no time to take effect.

If all species investigated are considered, the reduction in biting rate for *Anopheles* as a whole in the first month after DDT treatment was 19 per cent., for *Mansonia* and *Aedes* between 32 and 37 per cent., and for *Culex* 62 per cent. It seems possible that this contrast between *Anopheles* and *Culex* reflects a generic difference of behaviour not limited to Malaya. Figures from other countries seem scarce, but Muirhead Thomson (1950) indicates a reduction in biting by *A. gambiae* of about 15 per cent. following treatment with DDT, and D. Metselaar (personal communication) found about 20 per cent. for members of the group of *A. punctulatus* Dön.

Although Table III shows that, in the main, BHC and dieldrin had the same effect as DDT, depressing the biting rate much more in *C. p. fatigans* than in *A. maculatus* and *A. sundaicus*, there are some differences worth noting. The most obvious is that BHC, unlike DDT and dieldrin, did cause a large reduction in the biting rate of *A. maculatus*, at least for the first two months. Muirhead Thomson (1950) records a similar effect on *A. gambiae*. If *A. maculatus* did not touch the walls prior to biting, BHC must have acted by its particulate and fumigant effects; in any case the susceptibility of *A. maculatus* and the high toxicity and rapid action of BHC when fresh (Hadaway & Barlow, 1953) presumably account for the reduction in biting; large numbers of *A. maculatus* were killed before they could bite. With less susceptible species, such as *A. sundaicus* and *C. p. fatigans*, there was little difference between DDT and BHC.

The figures for *C. p. fatigans* show that the effect of the insecticides on the biting rate was prolonged with DDT, less so with BHC, and short-lived with dieldrin.

Effect of insecticides on resting behaviour.

The effect of the insecticides on resting behaviour of mosquitos is best illustrated by the figures for *C. p. fatigans*, since this species rests indoors to a considerable extent. The other species normally rest outside by day, so that even in an untreated hut the majority are found in the window trap in the morning. The figures are presented in Table IV.

The figures show that the behaviour of *C. p. fatigans* in an untreated hut was rather variable, but usually less than half of those caught were found in the window trap, the majority remained to rest in the hut. In the first month after

TABLE IV.

Effect on resting behaviour of mosquitos of deposits of 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft. Percentages of total found which were in the window trap.

Species	Insecticide	Before treatment	Weeks after treatment				
			1-4	5-8	9-12	13-16	17-20
							21-24
							25-28
<i>A. maculatus</i>	DDT	98	63	69	80	87	84
	BHC	96	71	84	92	91	97
	Dieldrin	97	95	99	98	98	99
	Control	93	96	96	94	95	98
	Mean	97					95
<i>A. sundatcus</i>	DDT	78	89	89	81	98	—
	BHC	74	86	78	96	—	—
	Dieldrin	79	96	86	75	67	74
	Mean	77					—
<i>C. p. fatigans</i>	DDT	56	87	80	79	79	66
	BHC	50	74	75	68	64	44
	Dieldrin	35	76	64	38	44	33
	Control	31	28	26	41	49	41
	Mean	48					41

* Based on small figures and not included in the graph (fig. 1).

treatment with DDT over 80 per cent. were in the window trap, and with BHC and dieldrin over 70 per cent. Clearly the insecticides had a strong tendency to drive *C. p. fatigans* out of the huts, and the same tendency is evident in the figures for *A. sundaicus* (77% in the window trap before treatment, 86 to 96% after treatment), and probably this tendency applies to all species. The figures

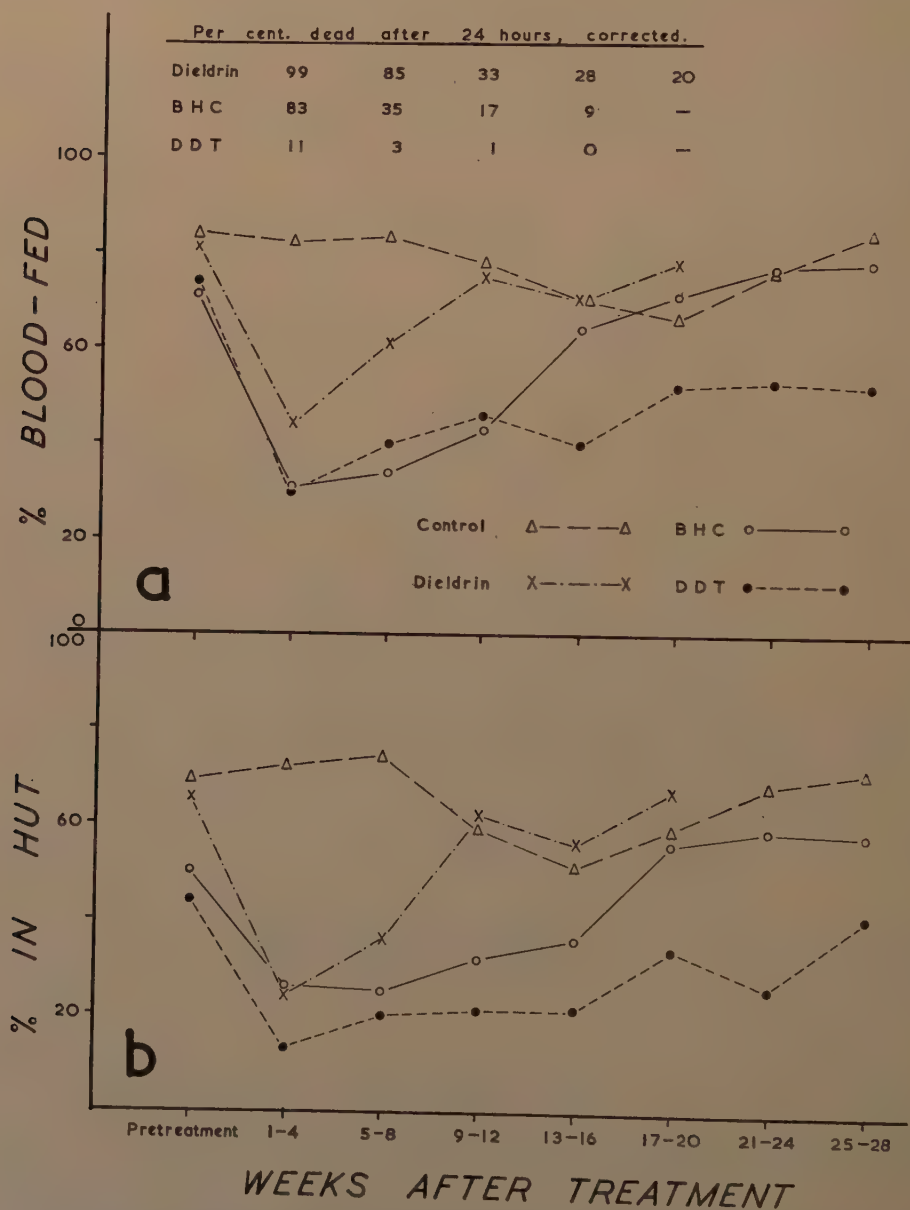


Fig. 1.—*C. p. fatigans*: effect of the insecticides on behaviour, (a) percentage blood-fed, (b) percentage remaining in the hut. The figures for the percentage dead after 24 hours are approximate means of the figures for Tampin and Kuala Lumpur (see fig. 3). Doses of 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

for *A. maculatus* look like an exception since there was a marked reduction, not an increase, in the numbers in the window trap after treatment with DDT and BHC. But evidently this was due to the rapid action of fresh DDT and BHC and the great susceptibility of *A. maculatus*, which caused many to die in the hut before they could reach the window trap (see Table VII); note that this did not occur with the slow-acting dieldrin.

The figures for *C. p. fatigans* show in the same way as did those for the biting rate, that the effect on resting behaviour was prolonged with DDT, less so with BHC, and shortest with dieldrin.

The African *A. gambiae* and *A. funestus*, like *C. p. fatigans*, normally rest indoors to a considerable extent, and treatment with DDT or BHC has the same effect of driving them into the window trap (Muirhead Thomson, 1950; Davidson, 1953). The effect is greatest with DDT and is more marked with both insecticides in the second month after treatment than in the first (Davidson), presumably because in the first month many are killed, like *A. maculatus*, before they can reach the window trap. In later months, as the insecticides age, the proportion in the window trap drops back again to normal.

Irritant effect of the insecticides.

The effect of the insecticides on the behaviour of *C. p. fatigans* is summarised by the two graphs in fig. 1, and a study of these reveals a marked difference between DDT and dieldrin, already briefly indicated in the two preceding sections on biting and resting behaviour. One sees from these graphs and the 24-hour kills entered above them, that DDT strongly depressed the proportion blood-fed and the proportion remaining in the hut throughout seven months after it had been applied and long after it had ceased to kill. There was a slow rise during this period, but both indices were still well below those of the control when the experiment ended. With dieldrin, on the other hand, these indices of behaviour had returned to normal (same level as the control) by the third month while the insecticide was still causing an appreciable kill. BHC was intermediate in effect. The figures for *A. sundaiacus* in Table IV display the same trend in a minor key; the proportion in the window trap increased after treatment (conversely the proportion in the hut decreased) and remained up with DDT, but soon returned to normal with dieldrin. Evidently this difference is due to the well-known irritant property of DDT, and a lack of it in dieldrin. Hadaway & Barlow (1953) have shown that DDT in any form activates mosquitos to flight in about 2-4 minutes, irrespective of whether they pick up a lethal dose or not. With dieldrin they found no such irritant effect (activation without kill), and mosquitos rested for more than 30 minutes on a dieldrin-treated surface, but all died within 24 hours. They found that fresh films of BHC, though not old ones, activated mosquitos more quickly than DDT, owing to the presence of the non-toxic δ isomer which has a rapid irritant action. However, all the mosquitos died soon after, due to the quick lethal effects of the γ isomer, which by itself activates at about the same speed as DDT.

Since dieldrin is non-irritant, the fall, during the first two months after treatment, in the percentage of *C. p. fatigans* biting and remaining in the hut must be due to the onset of fatal symptoms causing them to leave. As the dieldrin deposit ages, this onset is retarded so that it no longer influences the biting rate, and any effect on resting behaviour is not detected if the huts are searched early each morning, as they were in these trials.

Old deposits of BHC on unpainted wood lose much of their irritant effect (Hadaway & Barlow, 1953), though they may still be lethal as Wharton (1951a) has shown. He found small numbers of Anophelines resting by day in houses on wooden surfaces sprayed with BHC a few months before, but when kept for 24 hours many of these mosquitos died. There were virtually no mosquitos

resting in houses sprayed with DDT. If dieldrin is used for house spraying we may expect the same effect as with BHC, though more pronounced; living mosquitos are likely to be found within a few months of spraying, but for several months after that many of these mosquitos should die if kept under observation.

Conclusions on Behaviour.

In the preceding sections the effects of the insecticides upon different aspects of mosquito behaviour, such as biting and resting, have been discussed one by one, but this is only for simplicity. Overall behaviour as recorded in the huts is the resultant of interaction between the properties of the insecticides and the habits and susceptibilities of the mosquitos. The consequences of this interaction can be broadly summarised as follows, bearing in mind that all the mosquitos except *C. p. fatigans* normally rest outside by day, and that the Anophelines appear seldom to touch the walls before biting.

DDT influences behaviour mainly by persistent irritation, not by lethal action. *C. p. fatigans*, owing to its habits, is more affected than the other species, and a large proportion is prevented from biting and is driven out of the hut without being killed. DDT does not influence behaviour by rapid lethal action unless it is fresh and the mosquito is of a very susceptible species, e.g., *A. maculatus*, of which a considerable number are killed in the hut in the first two months after treatment, thus reducing the percentage reaching the window trap.

BHC, when fresh, influences behaviour by a blend of irritant and rapid lethal action in which it is scarcely possible to separate the two factors. The percentage of *A. maculatus* obtaining a blood-meal is considerably reduced by the rapid action of fresh BHC, where DDT and dieldrin are too slow to have much effect. With the less susceptible *A. sundaicus* there is no difference between BHC and DDT, both cause only a slight reduction in the percentage blood-fed. The effect of BHC on the behaviour of *C. p. fatigans* is much the same as that of DDT (reducing the number blood-fed and driving many out of the hut) but is less prolonged.

Dieldrin is non-irritant and influences the behaviour of mosquitos only by its lethal action. Since this is slow, behaviour is only noticeably influenced whilst the deposit is fresh, and even then the effect is less than with DDT or BHC. Dieldrin continues to kill after it has ceased to influence behaviour; DDT, on the contrary, influences behaviour after it has ceased to kill (see fig. 1).

One may sum up by saying that all three insecticides, either by lethal action or irritation or both, tend to reduce the biting rate and drive mosquitos out of a treated hut. But these tendencies may be much modified, or even quite obscured, according to the habits and susceptibilities of the species and the properties of the insecticide.

Kills.

The most useful figure for measuring the kill due to the insecticides is the percentage of mosquitos dead 24 hours after collection from a treated hut, corrected by Abbott's formula to allow for the death-rate among those from an untreated hut. At times (Wharton, 1951a) the death-rate after 48 hours has been employed, but in general it has been found unnecessary to keep mosquitos more than 24 hours, the additional kill due to the insecticides usually being slight and variable. On the other hand, except when the insecticide deposits are fresh, the immediate kill, i.e., the percentage of mosquitos which are dead when collected early in the morning, is only a fraction of the 24-hour kill and clearly it is necessary to keep mosquitos for some time after they have been collected from the hut.

The species investigated and their 24-hour death-rates when collected from

untreated huts are shown in Table V. The corrected 24-hour death-rates due to the insecticides are summarised by four-week periods in Table VI. It was arbitrarily assumed that a 24-hour kill of less than 50 per cent. would be insufficient, so most trials were stopped when it was clear that the kill had fallen permanently below this level. The doses per sq. ft. were 200 mg. DDT, 40 mg. γ BHC, or 40 mg. dieldrin, all as wettable powders. These doses correspond to 2.2 and 0.44 gm. per sq. metre.

TABLE V.

Twenty-four-hour mortalities of female mosquitos, mostly blood-fed, caught in huts prior to treatment with insecticides.

Species	Number found	Dead after 24 hr.	
		Number	Percentage
<i>Anopheles maculatus</i>	504	78	15
„ <i>sundaicus</i>	95	18	19
„ <i>barbirostris</i>	228	43	19
„ <i>letifer</i>	105	17	16
„ <i>umbrosus</i>	39	6	15
<i>Culex pipiens fatigans</i>	1298	100	8
„ spp.	233	30	13
<i>Mansonia</i> spp.	461	82	18
<i>Aedes albopictus</i>	55	7	13
„ <i>butleri</i>	83	20	24

These rates have been used to correct the post-treatment kills.

Differences between species.

The figures for *A. maculatus*, *A. sunaicus* and *C. p. fatigans* are plotted in figs. 2 and 3. The graphs show that there was a great difference in death-rates between *A. maculatus* and *C. p. fatigans*. The figures for *C. p. fatigans* at Tampin and on the coast near Kuala Lumpur have been presented separately as there appears to be some difference between them, the coastal strain showing even lower death-rates than that from Tampin. With *A. maculatus* the 24-hour kill due to DDT and BHC did not fall below 50 per cent. until nearly six months after treatment, whilst dieldrin was still killing over 80 per cent. in the seventh month. With *C. p. fatigans*, however, DDT never attained a 50 per cent. kill even in the first week after treatment against the more susceptible Tampin strain (Table XII), while the kills due to BHC and dieldrin, though high at first, fell below 50 per cent. after two months. *A. sunaicus* was intermediate.

There is no question of acquired resistance accounting for these striking differences and the rather long word "susceptibility" is used in discussion to avoid any confusion with resistance. Experimental errors due to differences in conditions from one trial to another also seem an unlikely explanation, for everything was standardised as far as possible, and moreover, species showing the most marked differences in death-rates were caught in the same hut at the same time, e.g., *A. maculatus* and *C. p. fatigans*, *A. sunaicus* and *C. p. fatigans*, *A. letifer* and *A. umbrosus*. There might be differences of behaviour which could cause differences between species not only in the timing of contact with the insecticides, as suggested on p. 442, but also in the amount of contact and therefore in their death-rates. If this were an important factor one might

TABLE VI.

Percentage kill after 24 hours (corrected) of mosquitoes that entered window-trap huts treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

Species	Weeks after treatment													
	1-4		5-8		9-12		13-16		17-20		21-24		25-28	
	DDT BHC Diel.		DDT BHC Diel.		DDT BHC Diel.		DDT BHC Diel.		DDT BHC Diel.		DDT BHC Diel.		DDT BHC Diel.	
<i>A. maculatus</i>	87	100 100	85	99 86	69	72 82	64	71 84	66	62 81	48	62 91	28	28 86
„ <i>sundaicus</i>	51	86 100	37	42 91	35	16 69	30	— 37	—	— 26	—	— —	—	— —
„ <i>barbirostris</i>	72	100 —	32	(100) —	(0)	64 —	—	(0) —	—	— —	—	— —	—	— —
„ <i>letifer</i>	40	100 —	30	(100) —	—	— —	—	— —	—	— —	—	— —	—	— —
„ <i>umbrosus</i>	88	(100) —	88	(100) —	—	— —	36	— —	57	— —	(70)	— —	—	— —
<i>C.p.fatigans</i> (T)*	19	96 100	4	60 89	0	17 37	—	9 37	—	— 29	—	— 33	—	— 15
„ <i>fatigans</i> (C)	5	72 99	1	9 79	1	— 24	0	— 14	—	— 5	—	— —	—	— —
<i>Culex</i> spp.	23	97 79	9	(0) 61	—	— 0	—	— 0	—	— 0	—	— —	—	— —
<i>Mansonia</i> spp.	70	96 100	55	76 94	43	(18) 22	34	(0) 27	37	— 5	15	— —	—	— —
<i>Aē. albopictus</i>	38	83 —	36	57 —	0	11 —	—	— —	—	— —	—	— —	—	— —
„ <i>butleri</i>	62	82 92	3	100 78	0	(100) 38	—	(74) 50	—	— 45	—	— —	—	— —

* T = Tampin, Negri Sembilan; C = Selangor coast.
Percentages in brackets are based on less than 10 mosquitoes caught.

expect *A. maculatus*, on account of its higher death-rate, to have much more contact than *C. p. fatigans*. However, in view of the indoor-resting habits of *C. p. fatigans* and the strongly contrasted outdoor-resting habits of *A. maculatus* this seems unlikely and one would expect instead that *C. p. fatigans* would tend to have more contact than *A. maculatus*. In fact there is so far no evidence of

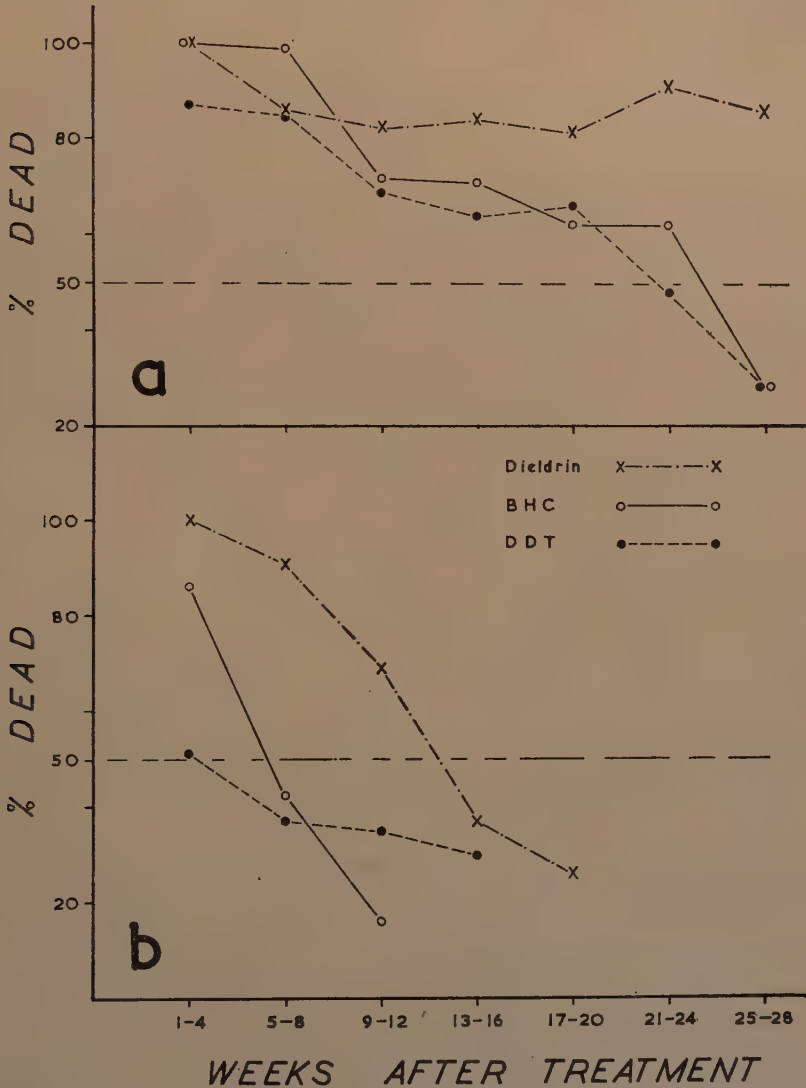


Fig. 2.—Percentage dead after 24 hours, corrected: (a) *A. maculatus*, (b) *A. sudaicus*.
Doses of 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

any great difference between species in the amount of contact while the insecticides are fresh, and with the irritant DDT even when it is no longer fresh; Hadaway & Barlow (1953) found no marked difference between the rates at which various species were activated by contact with the insecticides. Though

behaviour differences may play a part in the observed differences in the death-rates, a more likely explanation, for which there is substantial evidence, is that there are considerable innate physiological differences of susceptibility to the insecticides between different species. Wharton (1955) found in laboratory experiments that adult *C. p. fatigans* have an exceptionally low susceptibility to DDT, making them quite difficult to kill with this insecticide. The LD50 was more (probably much more) than 12 times that for *A. maculatus* which had

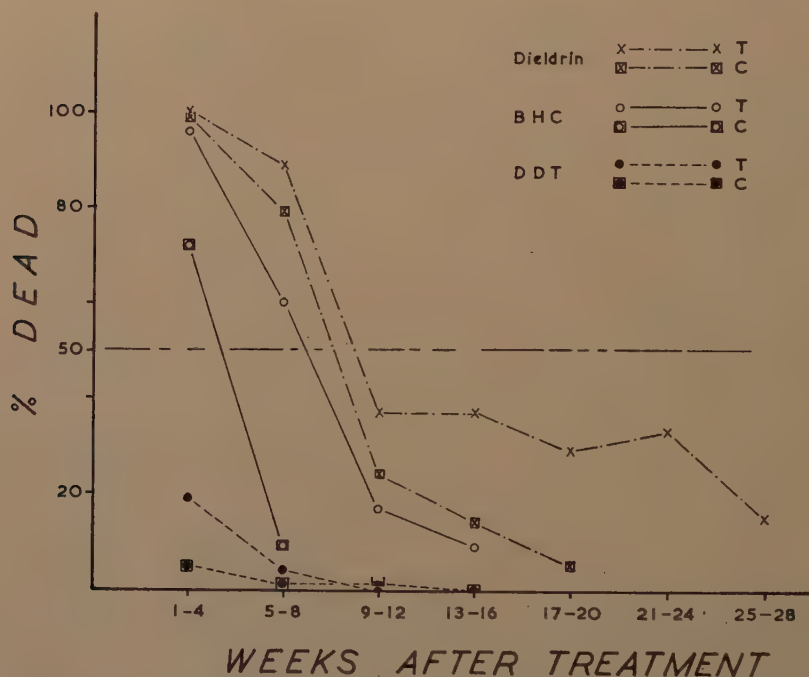


Fig. 3.—*C. p. fatigans* from two areas: Tampin (T), and the coast near Kuala Lumpur (C). Percentage dead after 24 hours, corrected. Doses of 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

almost the lowest LD50 amongst the species tested. This large difference may be quite enough to account for the widely different death-rates of the two species in the window-trap huts. Some of the rest of Wharton's figures, though not all of them, also agree well with the results recorded here. For example, Table VI in the present paper shows that *Aë. albopictus* was not easily killed by DDT, and Wharton found the LD50 of DDT for this species was rather high.

These differences in susceptibility were pointed out by Reid (1951b) on preliminary figures for DDT, and the addition of BHC and dieldrin has confirmed them. It seems that a species like *A. maculatus*, which is very susceptible to DDT, is likely to be susceptible also to BHC and dieldrin. Conversely, against a species like *C. p. fatigans* not readily killed by DDT, BHC and dieldrin are unlikely to remain effective for long. The correlation is only broadly true, but it does seem that a species is not likely to be very susceptible to one of these insecticides and insusceptible to another. Accordingly, we have tentatively grouped the species in Table VI in their order of susceptibility as shown below, even though the figures for some of them are incomplete:—

Tentative grouping of species according to susceptibility to insecticides used at the following doses per sq. ft.: 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin.

Susceptible

Corrected 24-hour kill not less than 50 per cent. for 5-6 months or more.

Anopheles maculatus
" *umbrosus*

Moderately susceptible

Corrected 24-hour kill not less than 50 per cent. for 1-4 months.

Anopheles barbirostris
" *letifer*
" *sundaicus*
Mansonia spp.
Aedes butleri

Slightly susceptible

Corrected 24-hour kill not reaching 50 per cent. with DDT; only above 50 per cent. for 1-2 months with BHC and dieldrin.

Culex pipiens fatigans
" spp.
Aedes albopictus

The disturbing conclusion is that most of these species are not very susceptible to the insecticides at the doses used. The question of what kill is necessary for control is discussed later (p. 456), but accepting for the moment that it should not be less than 50 per cent., then the list above suggests that these doses, if applied every six months in Malaya, would only be effective against *A. maculatus* and *A. umbrosus*. Against the other species more frequent application or higher doses would be needed, and this is unlikely to be economic except perhaps with dieldrin. One of us (R.H.W.) has recently found that dieldrin at 100 mg. per sq. ft. remains effective for six months against *Mansonia*.

It is difficult to compare our results with those of other workers who have used window-trap huts, as the figures are seldom strictly comparable. However, it is fairly clear from the work of Davidson (1953) and Wilkinson (1951) in East Africa that *A. gambiae* and *A. funestus* are susceptible species, against which all three insecticides maintain kills of not less than 50 per cent. for about six months or longer. Dieldrin, it is claimed, lasted almost two years (Macdonald & Davidson, 1953); this may be because it is non-irritant, and *A. gambiae* and *A. funestus* rest indoors by day (see remarks below about *C. p. fatigans*). *A. gambiae* seems a little less susceptible to DDT than *A. funestus*, but a little more susceptible to BHC and dieldrin. The figures for *A. minimus* Theo. in Assam published by Bertram (1950) and Gilroy (1951) suggest that this is also a susceptible species, but there is some uncertainty as their kills appear to be based on total mosquitos, or total Anophelines caught, irrespective of species. Downs & Bordas (1951) found both DDT and BHC had a very prolonged effect against *A. pseudopunctipennis* Theo. in Mexico, but the peculiar habits of this Anopheline, which rests indoors by day and bites outdoors at night, make it doubtful whether the kills can be compared with those for other species. The majority of the *A. pseudopunctipennis* caught were males, which might well be more easily killed than blood-fed females which make up the bulk of the catch with other *Anopheles*. In New Guinea, van Thiel & Metselaar (1955) obtained a kill of over 90 per cent. for the *A. punctulatus* group in the first five weeks after DDT treatment, which suggests that this species group will prove to be susceptible.

Davidson found, as we have, that *C. p. fatigans* is relatively insusceptible but he obtained better kills than ours, especially with dieldrin, which was still killing 69 per cent. after seven months, compared with our best kill which dropped from 89 to 37 per cent. between the second and third months. However, as he only collected live mosquitos remaining in the hut once a week instead of daily, and dieldrin is not irritant, there would be a tendency for the domestic *C. p. fatigans* to stay in the hut until killed. This may give a truer picture of what happens to *C. p. fatigans* in a house sprayed with dieldrin than our practice of catching mosquitos remaining in the hut every morning. It might account for

most of the difference between his results and ours, though his estimated dose was also a little higher than ours—50 mg. per sq. ft. compared with 40. There remains the possibility that there are strains of *C. p. fatigans* differing in susceptibility to insecticides; some evidence for this is provided by the experiments with the Tampin and coast strains (fig. 3) and by those of Reid (1955), who found appreciable differences in the LD₅₀'s of strains from different areas.

Differences between the insecticides.

It is clear from the graphs (figs. 2 and 3) that, irrespective of the species of mosquito, dieldrin was the most effective of the three insecticides; Davidson found the same. DDT and BHC, though effective against *A. maculatus*, do not seem promising for use in Malaya against *A. sundaeus* and *C. p. fatigans*. Against *A. maculatus* there is little to choose between them, though BHC appears slightly better; but in practice, in the control of malaria carried by *A. maculatus*, DDT gave slightly better results than BHC (Edeson & others, 1954).

A characteristic which the graphs bring out is that even when fresh, and with the susceptible *A. maculatus*, DDT never gave a complete kill. The less susceptible the species the lower was the initial kill, but the rate of decline in the kill with time seems to have been rather similar with all species, for the slope of the line is roughly the same for *A. maculatus*, *A. sundaeus* and *C. p. fatigans*. BHC and dieldrin behaved differently, for they gave a complete, or nearly complete, kill in the first month (it was 100 per cent. for all species in the first week) but the rate of decline in the kill varied greatly with the species. The less susceptible the species the more rapid was the decline and thus the steeper the line.

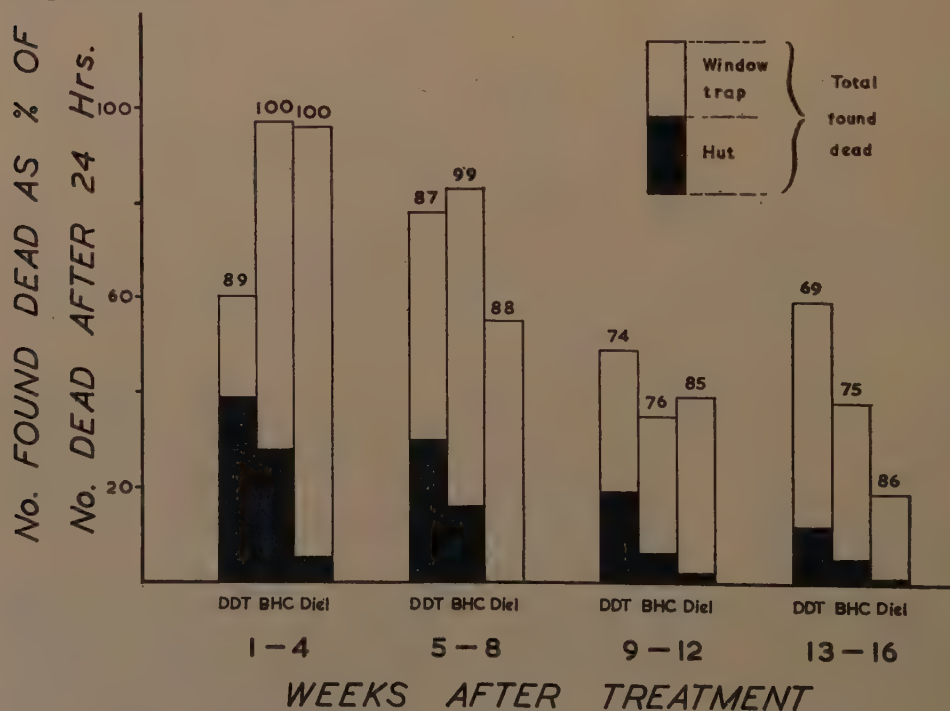


Fig. 4.—To compare the speed of action of the insecticides. *A. maculatus*: number found dead (in hut and window trap) as a percentage of the number dead after 24 hours. Figures on top of the columns are the percentages dead after 24 hours, uncorrected. Doses of 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

Speed of action.

In Table VII and fig. 4 the immediate kill (total found dead in hut and window trap) is compared with the 24-hour kill (both uncorrected) and from this some conclusions can be drawn about the speed of action of the insecticides. For example, though dieldrin is the most potent it was in general the slowest acting of the three. Even in the first month, when the 24-hour kill of *A. maculatus* due to dieldrin was 100 per cent., only 5 per cent. of the mosquitos were found dead in the hut; the rest all survived long enough to reach the window trap. With DDT and BHC in the first month, 39 and 28 per cent. of those *A. maculatus* which died in 24 hours were found dead in the hut. The rest of the figures in Table VII mostly tell the same story, and in the fourth month dieldrin, though it caused the highest 24-hour kill of *A. maculatus*, gave the lowest immediate kill. Hadaway & Barlow (1953) found dieldrin slow-acting.

It will be noticed from fig. 4 that DDT killed a higher proportion of *A. maculatus* in the hut than BHC. This is rather unexpected as fresh BHC kills more quickly than DDT and one would therefore expect it to have killed a larger proportion in the hut than DDT. This anomaly is probably the resultant of a number of variables, and it will suffice to mention some of the possible ones to illustrate the complexity of the subject without attempting a proper explanation. For example, the large reduction in the biting rate with fresh BHC, which was not evident with DDT (Table III), might have increased the number of *A. maculatus* reaching the window trap; it might be that unfed (BHC-affected) ones reached the window more easily than fed ones. Small particles of DDT, less than 10 μ , act much faster than larger ones; particle size is comparatively unimportant with BHC and dieldrin (Hadaway & Barlow, 1952); perhaps there was a large proportion of these small particles in the DDT used. If *A. maculatus* rested indoors by day the kill in the hut might have been higher with the more toxic and less irritant BHC than with DDT, as it is with the indoor-resting *A. gambiae*. Finally, the considerable differences between the insecticides in potency, speed of action, persistence, and irritant effect, and the changes in these factors with time, could readily have produced variations in the proportion of mosquitos dying in the hut compared with those dying in the window trap, and between the total of these two and the 24-hour kill.

The most important point which Table VII brings out is that the number of mosquitos found dead in the hut was only a small fraction of the total dying in 24 hours. With *A. maculatus* and DDT the figures averaged over the four months show that only 25 per cent. died in the hut. The corresponding figures for BHC and dieldrin are 14 and 2 per cent. With *C. p. fatigans* and dieldrin, i.e., an indoor-resting mosquito and a non-irritant insecticide, one might have expected a larger percentage dead in the hut (see p. 451); but presumably owing to the slow action of dieldrin, coupled with our practice of catching all mosquitos early in the morning, this figure was also low (between 17 and 9 per cent.). However, it was proportionately higher than with *A. maculatus* and *A. sundaicus*. Another important point is that after the second month the immediate kill (total found dead in hut and window trap in the morning) was commonly less than half of the 24-hour kill, especially with the slow-acting dieldrin.

One must conclude that no field method of assessing the effect of the insecticides which does not catch mosquitos escaping from a treated room and hold them, preferably for at least 24 hours, can give a correct estimate of the kill.

Effect of light doses.

Up to now we have been discussing the effect of heavy doses of the insecticides, chosen primarily to last six months in houses, against *A. maculatus*. Some trials were also made with lighter doses for purposes of comparison. The results

TABLE VII.

Percentage immediate kill (found dead in hut and window trap) compared with 24-hour kill (both uncorrected), of *A. maculatus*, *A. sundaiacus* and *C. p. fatigans* * that entered window-trap huts treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft., during 16 weeks after treatment.

	Species	Weeks after treatment											
		1-4			5-8			9-12			13-16		
		DDT	BHC	Diel.	DDT	BHC	Diel.	DDT	BHC	Diel.	DDT	BHC	Diel.
Per cent. dead after 24 hr.	<i>A. maculatus</i>	89	100	100	87	99	88	74	76	85	69	75	86
	<i>A. sundaiacus</i>	60	89	100	49	53	93	47	32	75	43	—	49
	<i>C. p. fatigans</i>	13	74	99	9	16	81	9	—	30	4	—	21
Found dead in hut as per cent. of no. dead after 24 hr.	<i>A. maculatus</i>	39	28	5	30	16	0	19	6	2	12	5	1
	<i>A. sundaiacus</i>	13	6	1	13	2	5	12	13	4	0	—	0
	<i>C. p. fatigans</i>	17	25	17	22	17	17	21	—	14	8	—	9
Found dead in hut and window trap as per cent. of no. dead after 24 hr.	<i>A. maculatus</i>	60	97	96	73	83	55	49	35	39	59	38	19
	<i>A. sundaiacus</i>	63	35	78	49	42	65	48	50	21	41	—	0
	<i>C. p. fatigans</i>	72	77	88	78	59	65	63	—	29	58	—	14

* Figures from Selangor.

are shown in fig. 5, which is based on Table IX. As will be seen from that Table the numbers for DDT are small, and this probably accounts for the irregular curve on the graph. However, it looks as if with larger numbers the curve would have cut the 50 per cent. mortality line about the third month. In other

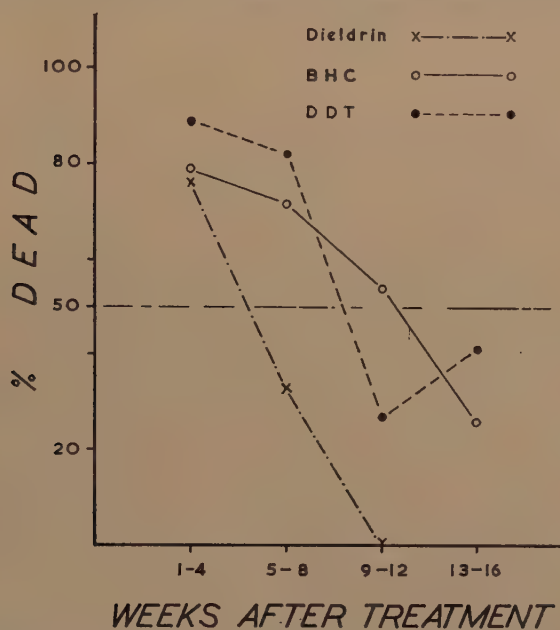


Fig. 5.—Effect of low doses. *A. maculatus*: percentage dead after 24 hours, corrected. Doses of 100 mg. DDT, 10 mg. γ BHC or 10 mg. dieldrin per sq. ft.

words DDT at a dosage of 100 mg. per sq. ft. probably gives about the same result as did γ BHC at 10 mg., the 24-hour kill of *A. maculatus* falling below 50 per cent. after about three months. Rather surprisingly, 10 mg. dieldrin rapidly lost its effect. This is perhaps a further reason for thinking that high doses of dieldrin deserve a trial (see p. 451). Davidson (1953) had similar results with light doses of DDT and BHC against *A. gambiae* and *A. funestus*; significant kills lasted only about 1-3 months. Against the Malayan species other than *A. maculatus* and *A. umbrosus* none of these light doses would be of much practical use.

Conclusions on Kills.

Our conclusions about the killing powers of the insecticides themselves are in agreement with those of other workers. We have found that DDT is less toxic than BHC and dieldrin, and that unlike them it never gives a complete kill even when fresh. Dieldrin, though slow-acting, is the most effective of the three, and as it is non-irritant it should prove particularly lasting against the indoor-resting species of other countries, provided it is not neutralised by sorption into mud surfaces.

Less well known, but perhaps more important, are the large differences we have found between species of mosquitos in their susceptibility to the insecticides. Using doses per sq. ft. of 200 mg. DDT, 40 mg. γ BHC and 40 mg. dieldrin, the 24-hour death-rate of a susceptible species like *A. maculatus* remains above 50 per cent. for about six months or more. But with a very insusceptible species

like *C. p. fatigans*, DDT scarcely kills any, while BHC loses its effect in a few weeks, and dieldrin does not last much longer. There are all degrees of susceptibility between the extremes represented by these two species, but evidently the majority of vectors in Malaya are not very susceptible, and it seems unlikely that these doses of the insecticides would be effective for their control. Large doses of dieldrin seem to offer the best hope.

Discussion.

The trials reported here have been more a test of the species investigated than a test of the insecticides. The properties of the insecticides can be evaluated in the laboratory, and when they are tried in the field the new element in the situation is the wild mosquito. In our trials dieldrin has proved superior to DDT and BHC, but this was already known from laboratory work, and our results do little more than confirm this. What is important in our findings, and which could not be learnt in the laboratory, is the wide range of susceptibility of different species under field conditions; particularly the fact that, with what are usually considered high doses of the insecticides, the kills of many species were too low, or lasted too short a time, for practical purposes. With species likely to make frequent contact with the insecticides these low kills might be sufficient, but not with species having only occasional contact, *i.e.*, all those investigated except *C. p. fatigans*.

We have said above that the kills of many species were too low for practical purposes. This statement needs justifying, and this requires a knowledge of what kills are necessary to control malaria. We adopted an arbitrary criterion and considered a kill of 50 per cent. in 24 hours as the lower limit of effectiveness. Are there any rational grounds for this? Macdonald & Davidson (1953), in a valuable review of the effects of insecticides on mosquitos, have considered this question. They point out that malaria may be controlled by residual insecticides with kills that fall far short of elimination of the mosquito, provided that such kills reduce its expectation of life below the critical level for malaria transmission, and in an interesting Table they suggest the kills necessary for control under various conditions. But their suggested kills are based on the assumption that the mosquito enters a treated shelter not less often than one day in two,* and they emphasise that species which enter much less frequently than this will be very difficult to control with residual insecticides.

It is clear that with entry not less often than one day in two, half the adult mosquito population will come in contact with the insecticide every 24 hours, and even a low kill on each occasion of entry will affect the expectation of life of the whole population, but if entry is very infrequent even a high kill on each occasion will have little effect on the average expectation of life. This is important because there are reasons for thinking that, in many rural areas in Malaya, *A. maculatus* only enters a treated shelter about once in ten days, especially in the diffuse Malay villages (kampongs) where residual insecticides offer the only practical means of malaria control. Wharton (1953a) has shown that at one place where both men and cattle were available, not more than 20 per cent. of *A. maculatus* fed on man; the average was only 13.5 per cent. That is to say, not more than one meal in five would be human blood, and with two days between meals, a human blood-meal (assumed to involve entry into a house) would be taken about once in ten days. This is assuming that *A. maculatus* is homogeneous, rather than a mixture of distinct man-biting and cattle-biting

* They term this "medium endophilism"; entry every day, whether to rest or to bite, they call "complete endophilism". Senior-White (1954) restricts the terms endophilism and exophilism to describing the day-resting habits; he uses separate terms to describe the feeding habits. For purposes of contact with a residual insecticide it probably does not matter why a mosquito enters a treated shelter, but in view of possible confusion we have preferred to avoid these terms.

rates which hardly seems likely. Wharton was working on a rubber estate, and in such places the Indian labourers usually keep their cattle in sheds which could have been sprayed, but in Malay kampongs, though cattle are common, there are usually no cattle sheds, and virtually only the houses can be sprayed. Since *A. maculatus* enters shelters only to feed (and prefers to feed outdoors) this would reduce its contact with residual insecticides in kampongs to the occasions when it seeks human blood, i.e., about once in ten days. When contact with the insecticide is as infrequent as this, even a 100 per cent. kill on entry will have little effect on the expectation of life of the population as a whole; there will merely be a 10 per cent. reduction in numbers. This agrees with the field-control results (Edeson & others, 1954) which showed that spraying had very little effect on *A. maculatus* beyond causing a slight reduction in numbers of adults.

In this situation it seems better to forget about the total population of *A. maculatus* which we cannot much affect, and consider only those which enter houses. Provided that people sleep indoors, and that only a minor amount of transmission takes place outdoors, we may hope to reduce malaria by residual spraying, even though we cannot substantially reduce the numbers of the vector. This is what happened in our field control experiments, and has happened also in Venezuela (Gabaldon & Berti, 1954). Assuming for simplicity that all transmission takes place indoors, then a 50 per cent. kill of mosquitos entering treated houses should about halve transmission; the reasoning is as follows. Since in the presence of cattle *A. maculatus* probably enters houses only about once in ten days, it is unlikely to come in contact with insecticide (if there are no treated shelters other than the houses) except on the occasion of acquiring infection, and some 10 or more days later when transmitting the infection for the first time. But on the second occasion it will probably deliver the infective bite before touching the insecticide (see p. 442), which therefore acts on transmission mainly by killing mosquitos when they rest on treated walls after the first or infecting meal. Thus if the insecticide kills 50 per cent. of mosquitos entering, the number acquiring an infection and living to mature it will be halved. The fact that the infective mosquito may be killed after transmitting for the first time may further reduce transmission, but such reduction will probably be slight, because with entry into houses only once in ten days few mosquitos (excluding interrupted feeding the first time) are likely to live long enough to transmit a second time, irrespective of the presence or absence of insecticide. Transmission occurring outdoors probably outweighs this factor, and it seems likely that a 50 per cent. kill will not in practice reduce transmission by as much as a half. Any lesser degree of control than this hardly seems worthwhile, and so we feel that a 50 per cent. 24-hour kill is a reasonable standard to adopt as the lower limit of effectiveness, at least under conditions such as ours where mosquitos rest and feed mostly outdoors, and the overall population is little affected by spraying. Under these conditions the optimum kill on entry would appear to be 100 per cent. In the control experiments (Edeson & others, 1954), transmission, as judged by infant infections, was reduced by about two-thirds by DDT, which presumably killed somewhere between 50 and 80 per cent. of *A. maculatus* entering sprayed houses, if the trap-hut results are taken as a guide.

The possibility of encouraging people to erect cattle sheds which could be sprayed, so as to increase the contact of *A. maculatus* with the insecticide, will have to be considered and balanced against any increased risk of resistance developing. For, supposing that *A. maculatus* is potentially able to develop resistance, there still seems little risk while houses alone are sprayed, because the proportion of the *A. maculatus* population having contact with insecticide is probably too small. But any large increase in this contact might make resistance a possibility. It is for this reason that the use of DDT, etc., as a

larvicide may involve a greater risk of inducing resistance than its use for house spraying, for with efficient application of larvicide a high proportion of the larval population will have contact with the insecticide.

It may be useful to end this discussion on a more general note. The principal factors determining the degree of control that will be achieved by a residual insecticide are the two recognised by Macdonald & Davidson (1953), namely, the kill on each occasion of entry into a treated shelter, and the frequency of entry. This second factor, more broadly defined as amount of contact with insecticide, has been widely recognised for some time as of great importance, and depends mainly on the habits of the mosquito. It is a matter of observation that species which habitually bite man in preference to animals, and which rest indoors by day, are usually the most severely affected by house spraying, even to the point of eradication, as for example *A. darlingi* Root and *Aë. aegypti*.

The first factor, the kill on each occasion of contact with insecticide, has received less attention. There has been a tendency to assume that all Anophelines, and in fact most mosquitos other than *Culex pipiens fatigans*, are readily killed by the insecticides in use. Our results suggest that this is by no means true, and that quite a number of important species have too low a susceptibility to be effectively controlled by the usual doses of DDT or BHC, especially when contact is infrequent. It must be remembered that the kill is not merely a function of the potency of the insecticide, but also of the susceptibility of the mosquito, which may vary widely between species. Even that is not all; other characteristics of the insecticide besides potency, such as irritance, in combination with the resting habits of the mosquito, may affect the kill. For example, even if DDT were as toxic to *C. p. fatigans* as dieldrin, it would probably not be as effective because its irritating effect would prevent lengthy contact.

Evidently the two main factors in control, the kill on each occasion of contact, and the amount of contact, are themselves complex, and it might not be easy to summarise in a simple fashion all the factors determining the degree of control achieved. Perhaps, however, most of the mosquito factors can be summarised under three heads:

- (a) *Susceptibility*, of which an estimate could be obtained from comparative laboratory measurements of the LD50 of the insecticides for different species, but which is better determined with window-trap huts as well.
- (b) *Frequency of contact*, which depends largely on frequency of entry, which in turn depends on habits.
- (c) *Duration of contact on each occasion of entry*, which depends mainly on whether the mosquito rests indoors by day, and whether the insecticide is irritant. This is chiefly important as the insecticide deposit ages and long contact periods are required to kill.

Summary.

Trials are described with window-trap huts to test residual insecticides against vector mosquitos in Malaya. DDT, BHC and dieldrin were tested as wettable powders against *Anopheles maculatus* Theo., *A. sundaicus* (Rdnw.) and *Culex pipiens fatigans* Wied. Some results were also obtained with *Anopheles barbirostris* Wulp, *A. letifer* Sandosham and *A. umbrosus* (Theo.), with species of *Culex* other than *C. p. fatigans*, with species of *Mansonia*, and with *Aëdes albopictus* (Skuse) and *Aë. butleri* Theo. All these mosquitos, except *C. p. fatigans*, are essentially outdoor species which enter houses only to bite, and which feed freely on animals as well as on man.

The validity of the window-trap hut method is discussed. It is concluded that although some mosquitos escape through the entrance louvres, and a treated hut is not quite the same as a treated and occupied room, the kills recorded are a good guide to the kills that may be expected in treated houses.

It is shown that there is usually some reduction, seldom sufficient to be important, in the number of mosquitos entering the huts in the first few weeks after treatment. This is probably due to air-borne particles of insecticide drifting through the louvres and acting on mosquitos waiting to enter.

The effect of treatment on the biting and resting behaviour of the mosquitos varied widely, being due to a combination of the properties of the particular insecticide and the habits and susceptibilities of the different species. Broadly speaking, all three insecticides tended to reduce the proportion of mosquitos obtaining a blood-meal, and the proportion remaining in the hut in the morning. But these tendencies might be modified or quite obscured by particular characteristics of the mosquito species or of the insecticide. Thus, for example, the percentage of *A. maculatus* obtaining a blood-meal was only reduced by 11 per cent. in the first month after treatment with DDT, compared with a 60 per cent. reduction in *C. p. fatigans*. It is suggested that perhaps *A. maculatus* did not touch the treated walls before biting and *C. p. fatigans* did. This difference applies to other species of *Anopheles* and *Culex*, and the average reductions in biting rate for the two genera were 19 and 62 per cent.

As another example, before treatment rather more than half of the *C. p. fatigans*, an indoor-resting species, remained in the hut; after treatment with DDT, which does not easily kill *C. p. fatigans*, over 80 per cent. were found in the window trap. By contrast, in the outdoor-resting species, *A. maculatus*, which is easily killed by DDT, over 90 per cent. were in the window trap before treatment, and fewer after treatment. The effect of DDT (and BHC) was to kill some of the *A. maculatus* before they could leave the hut, thereby reducing the proportion reaching the window trap to about 70 per cent. There was no reduction in the percentage of *A. maculatus* reaching the window trap with the slow-acting dieldrin.

Judged chiefly by the effect upon *C. p. fatigans*, DDT influenced mosquito behaviour mainly by its irritant effect, which persisted after the insecticide was no longer killing. The effect of BHC upon behaviour was due to a combination of irritance and rapid lethal action, but this did not last as long as the effect of DDT. Dieldrin has no irritant effect and it influenced behaviour only by lethal action for a short time while it was fresh; it continued to kill after it was no longer doing so rapidly enough to affect behaviour.

The most important finding was the wide range of susceptibility to the insecticides among the ten species or groups of species tested, and the fact that only two (*Anopheles maculatus* and *A. umbrosus*) seemed susceptible enough to be effectively controlled in practice by the fairly heavy doses used (200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin) per sq. ft. With *A. maculatus* (and probably *A. umbrosus*) the 24-hour kill remained above 50 per cent. for about six months or more. With *A. sundaicus* (and probably *A. barbirostris*, *A. letifer*, *Mansonia* and *Aë. butleri*) the 24-hour kill fell below 50 per cent. in from one to four months. With *C. p. fatigans* (and probably *Culex* spp. and *Aë. albopictus*) the kill never reached 50 per cent. with DDT, and was only above 50 per cent. for one to two months with BHC and dieldrin.

A. maculatus was the most susceptible species to all three insecticides and *C. p. fatigans* the least; the latter was particularly insusceptible to DDT.

Heavier doses of dieldrin might be effective against the less susceptible species, and a dose of 100 mg. per sq. ft. has been found to remain effective for six months against *Mansonia*.

Except for the trial with light doses, dieldrin gave the best results against all species. When fresh it gave kills as high as or higher than those of BHC, and it remained effective longer than DDT or BHC.

Dieldrin and BHC when fresh gave complete or nearly complete kills of all species, but the rate of decline in the kills with time varied widely, and was

quickest with the least susceptible species. With DDT, on the other hand, the rate of decline in the kill seemed to be roughly the same with all species, and it was the initial kill which varied. For the least susceptible group of species this was well under 50 per cent. in the first month, and was only 5 per cent. with one strain of *C. p. fatigans*; with the most susceptible it was between 80 and 90 per cent.; it never reached 100 per cent.

Few mosquitos were found dead in treated huts, the great majority escaped into the window traps, especially with the slow-acting dieldrin. With *A. maculatus* in the first four months after treatment with DDT, only 25 per cent. of those dying in 24 hours were found dead in the hut. With BHC and dieldrin the corresponding figures were 14 and 2 per cent. The immediate kill (total found dead in the hut and window trap in the morning) was commonly less than half of the 24-hour kill. These results clearly show the importance of using window traps and holding mosquitos, if possible for 24 hours, if a reliable estimate of the effect of the insecticides is required.

Light doses (100 mg. DDT, 10 mg. γ BHC or 10 mg. dieldrin per sq. ft.) were tried against *A. maculatus*; DDT and BHC remained effective for three months, but dieldrin only for one month.

The performance of the insecticides at the higher doses can be characterised by saying that DDT is irritant and persistent, but not toxic enough except to the most susceptible of the species tested. BHC is irritant when fresh, though it kills at the same time; it is very toxic to all species, but does not remain effective long enough except against the most susceptible ones. Dieldrin is slower acting than DDT and BHC, but is non-irritant, very toxic, and remains effective longer; against less susceptible species higher doses than 40 mg. per sq. ft. will be needed. In countries where vector species rest indoors by day, dieldrin may prove particularly lasting because mosquitos will rest on treated surfaces for long periods.

The probable relation is discussed between the kills recorded in our window-trap huts, and the degree of malaria control that may be expected when houses are sprayed. The kill necessary to control malaria depends to a large extent on how much contact the vector has with the insecticide. If its habits bring it into frequent contact with treated surfaces, a comparatively low kill on each occasion of contact may greatly reduce the population of the vector and suffice to control malaria. But if contact is infrequent, as may be expected with species of *Anopheles* such as those studied, which rest outdoors and feed only to a limited extent on man, then a high kill on each occasion of entry into treated houses is needed to control malaria, and there may be very little effect on the population of the vector. In these circumstances a 24-hour kill of 50 per cent., which is here considered the lower limit of effectiveness, seems a reasonable figure to adopt.

The mosquito factors which affect the degree of control achieved with residual insecticides can be thought of under three headings: (a) *susceptibility to the insecticide*, which largely determines the kill on each occasion of contact, and which we have shown may vary widely with different species, and is often quite low; (b) *frequency of contact*, which depends on habits, as these determine frequency of entry into treated shelters; (c) *duration of contact on each occasion of entry*, which is important when the insecticide deposit is no longer fresh, and depends mainly on whether the mosquito rests indoors by day and whether it is irritated by the insecticide.

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References.

- ANDERSON, R. E. (1954). Annual report of the Malaria Advisory Board (Malaya) for the year 1953, p. 3.
- BERTRAM, D. M. (1950). A critical evaluation of DDT and "Gammexane" in malaria control in upper Assam over five years, with particular reference to their effect on *Anopheles minimus*.—Ann. trop. Med. Parasit., **44**, pp. 242–254.
- DAVIDSON, G. (1953). Experiments on the effect of residual insecticides in houses against *Anopheles gambiae* and *A. funestus*.—Bull. ent. Res., **44**, pp. 231–254.
- DOWNES, W. G. & BORDAS, E. (1951). Control of *Anopheles pseudopunctipennis* in Mexico with DDT residual sprays applied in buildings. Part V. Effectiveness of residual applications of DDT and Gammexane up to one year after application under controlled conditions.—Amer. J. Hyg., **54**, pp. 150–156.
- EDESON, J. F. B., WHARTON, R. H., WILSON, T. & REID, J. A. (1954). Final report to the Colonial Insecticides, Fungicides and Herbicides Committee, and the Colonial Medical Research Committee, on experiments in rural malaria control in Malaya, 1948–1952.—Rep. Inst. med. Res. Malaya, no. 39, 97 pp., multigraph.
- FIELD, J. W. & REID, J. A. (1951). Malaria.—Stud. Inst. med. Res. Malaya, no. 25, pp. 127–177.
- GABALDON, A. & BERTI, A. L. (1954). The first large area in the tropical zone to report malaria eradication: north-central Venezuela.—Amer. J. trop. Med. Hyg., **3**, pp. 793–807.
- GILROY, A. B. (1951). Field trials of DDT and BHC in Assam.—Indian J. Malariol., **5**, pp. 171–182.
- HADAWAY, A. B. & BARLOW, F. (1952). Studies on aqueous suspensions of insecticides. Part III. Factors affecting the persistence of some synthetic insecticides.—Bull. ent. Res., **43**, pp. 281–311.
- HADAWAY, A. B. & BARLOW, F. (1953). Studies on aqueous suspensions of insecticides. Part IV. The behaviour of mosquitos in contact with insecticidal deposits.—Bull. ent. Res., **44**, pp. 255–271.
- KENNEDY, J. S. (1947). The excitant and repellent effects on mosquitos of sublethal contacts with DDT.—Bull. ent. Res., **37**, pp. 593–607.
- MACDONALD, G. & DAVIDSON, G. (1953). Dose and cycle of insecticide applications in the control of malaria.—Bull. World Hlth Org., **9**, pp. 785–812.
- MUIRHEAD THOMSON, R. C. (1947). The effects of house spraying with pyrethrum and with DDT on *Anopheles gambiae* and *A. mclasi* in West Africa.—Bull. ent. Res., **38**, pp. 449–464.
- MUIRHEAD THOMSON, R. C. (1950). DDT and Gammexane as residual insecticides against *Anopheles gambiae* in African houses.—Trans. R. Soc. trop. Med. Hyg., **43**, pp. 401–412.
- NAIR, C. P. (1949a). Investigations on DDT barrier spray in *A. letifer* areas.—Indian J. Malariol., **3**, pp. 119–127.

- NAIR, C. P. (1949b). Effect of DDT barrier spray in *A. sundanicus* area in Malaya.—Med. J. Malaya, **3**, pp. 198–203.
- RAJINDAR PAL, SHARMA, M. I. D. & KRISHNAMURTHY, B. S. (1952). Studies on the development of resistant strains of house-flies and mosquitoes.—Indian J. Malariol., **6**, pp. 303–316.
- REID, J. A. (1947). A preliminary note on Malayan forms of *Anopheles barbirostris*.—Med. J. Malaya, **2**, pp. 125–127.
- REID, J. A. (1951a). A laboratory method for testing residual insecticides against Anopheline mosquitoes.—Bull. ent. Res., **41**, pp. 761–777.
- REID, J. A. (1951b). Effects of DDT upon different species of mosquitoes in Malaya.—Nature, Lond., **168**, pp. 863–865.
- REID, J. A. (1954). A preliminary *Aedes aegypti* survey.—Med. J. Malaya, **9**, pp. 161–168.
- REID, J. A. (1955). Resistance to insecticides in the larvae of *Culex fatigans* in Malaya.—Bull. World Hlth Org., **12**, pp. 705–710.
- REID, J. A. & HODGKIN, E. P. (1950). The *Anopheles umbrosus* group (Diptera: Culicidae). Part I.—Trans. R. ent. Soc. Lond., **101**, pp. 281–334.
- SENIOR-WHITE, R. (1954). Adult Anopheline behaviour patterns: a suggested classification.—Nature, Lond., **173**, p. 730.
- TARZWELL, C. M. & STIERLI, H. (1945). The evaluation of DDT residual sprays for the control of Anopheline mosquitoes in dwellings.—Publ. Hlth Rep., suppl. no. 186, pp. 35–48.
- VAN THIEL, P. H. & METSELAAR, D. (1955). A pilot project of residual spraying as a means of controlling malaria transmitted by Anophelines of the *punctulatus* group in Netherlands New Guinea.—Docum. Med. geogr. trop., **7**, pp. 164–181.
- WALLACE, R. B. (1948). Insecticides and *A. maculatus*.—Med. J. Malaya, **3**, pp. 5–33.
- WALLACE, R. B. (1950). Further observations on insecticides and *A. maculatus*.—Med. J. Malaya, **5**, pp. 115–139.
- WHARTON, R. H. (1951a). DDT and BHC as residual insecticides in Malaya.—Nature, Lond., **167**, pp. 854–855.
- WHARTON, R. H. (1951b). The behaviour and mortality of *Anopheles maculatus* and *Culex fatigans* in experimental huts treated with DDT and BHC.—Bull. ent. Res., **42**, pp. 1–20.
- WHARTON, R. H. (1951c). The habits of adult mosquitoes in Malaya. I. Observations on Anophelines in window-trap huts and at cattle-sheds.—Ann. trop. Med. Parasit., **45**, pp. 141–154.
- WHARTON, R. H. (1953a). The habits of adult mosquitoes in Malaya. III. Feeding preferences of Anophelines.—Ann. trop. Med. Parasit., **47**, pp. 272–284.
- WHARTON, R. H. (1953b). The habits of adult mosquitoes in Malaya. IV. Swarming of Anophelines in nature.—Ann. trop. Med. Parasit., **47**, pp. 285–290.
- WHARTON, R. H. (1955). The susceptibility of various species of mosquitoes to DDT, dieldrin and BHC.—Bull. ent. Res., **46**, pp. 301–309.

WHARTON, R. H. & REID, J. A. (1950). DDT and "Gammexane" as residual insecticides against *Anopheles maculatus* in Malaya.—Nature, Lond., **165**, pp. 28-29.

WILKINSON, P. R. (1951). Distribution and fate of *Anopheles gambiae* and *A. funestus* in two different types of huts treated with DDT and BHC in Uganda.—Bull. ent. Res., **42**, pp. 45-54.

WILSON, T. & REID, J. A. (1951). Filariasis.—Stud. Inst. med. Res. Malaya, no. 25, pp. 209-227.

APPENDIX.

Summarised Figures, of all Trials made, from which all Tables and Graphs in the Text can be derived.

TABLE VIII.

Behaviour and mortality of *Anopheles maculatus* that entered window-trap huts untreated (control) or treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

	Insecticide	Before treatment	Weeks after treatment						
			1-4	5-8	9-12	13-16	17-20	21-24	25-28
Total found	DDT	120	153	225	414	444	472	131	38
	BHC	73	103	157	183	212	111	56	23
	Dieldrin	88	43	86	155	162	146	37	16
	Control	60	207	172	608	701	337	104	65
Found dead	DDT	1	82	153	150	182	199	28	6
	BHC	2	100	129	48	61	25	8	0
	Dieldrin	2	41	42	51	27	18	4	3
	Control	0	4	2	22	15	14	1	0
Found dead in hut	DDT	0	53	58	57	38	60	7	2
	BHC	0	29	25	8	8	1	1	0
	Dieldrin	0	2	0	2	1	1	0	0
	Control	0	0	0	1	1	0	0	0
Dead after 24 hr.	DDT	14	136	196	305	308	336	73	15
	BHC	13	103	156	139	159	75	38	9
	Dieldrin	10	43	76	132	140	123	34	14
	Control	11	60	31	88	54	31	7	5
Blood-fed	DDT	109	125	183	326	326	348	111	34
	BHC	67	46	87	162	185	100	50	23
	Dieldrin	85	37	82	142	140	122	33	15
	Control	52	187	157	503	624	307	101	63
Blood-fed in window trap	DDT	107	78	123	257	277	295	101	31
	BHC	64	30	72	147	167	97	41	22
	Dieldrin	82	35	82	139	136	121	33	15
	Control	48	175	151	468	587	300	96	61
Total in window trap	DDT	118	96	155	331	388	396	121	35
	BHC	70	74	132	168	192	108	47	22
	Dieldrin	85	41	86	152	158	144	37	16
	Control	56	198	165	572	662	329	99	61

TABLE IX.

Mortality of *Anopheles maculatus* that entered window-trap huts treated with low doses of insecticides; 100 mg. DDT, 10 mg. γ BHC or 10 mg. dieldrin per sq. ft.

	Insecticide	Before treatment	Weeks after treatment			
			1-4	5-8	9-12	13-16
Total found	DDT	56	11	13	8	24
	BHC		90	87	33	16
	Dieldrin	107	34	116	111	—
Dead after 24 hr.	DDT	21	10	11	3	12
	BHC		74	66	20	6
	Dieldrin	9	27	50	17	—
Per cent. dead after 24 hr., corrected for 15 per cent. dead in controls (Table V)	DDT		89	82	27	41
	BHC		79	72	54	26
	Dieldrin		76	33	0	—

TABLE X.

Behaviour and mortality of *Anopheles sudaicus* that entered window-trap huts treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

	Insecticide	Before treatment	Weeks after treatment				
			1-4	5-8	9-12	13-16	17-20
Total found	DDT	18	255	292	303	148	—
	BHC	53	71	255	120	—	—
	Dieldrin	24	158	117	106	81	53
Found dead	DDT	0	93	70	69	26	—
	BHC	5	22	57	19	—	—
	Dieldrin	0	123	71	17	0	0
Found dead in hut	DDT	0	19	18	17	0	—
	BHC	2	4	3	5	—	—
	Dieldrin	0	1	5	3	0	0
Dead after 24 hr.	DDT	2	152	143	143	64	—
	BHC	14	63	135	38	—	—
	Dieldrin	2	158	109	80	40	21
Blood-fed	DDT	13	192	233	232	93	—
	BHC	49	55	195	91	—	—
	Dieldrin	19	135	107	95	75	48
Blood-fed in window trap	DDT	9	174	204	184	91	—
	BHC	35	46	156	82	—	—
	Dieldrin	15	129	92	70	45	35
Total in window trap	DDT	14	226	261	245	145	—
	BHC	39	61	199	115	—	—
	Dieldrin	19	151	100	80	54	39

TABLE XI.

Behaviour and mortality of *Anopheles barbirostris*, *A. letifer* and *A. umbrosus* that entered window-trap huts treated with 200 mg. DDT or 40 mg. γ BHC per sq. ft.

	Species	Insecticide	Before treatment	Weeks after treatment					
				1-4	5-8	9-12	13-16	17-20	21-24
Total found	<i>A. barbirostris</i>	DDT BHC	145 83	87 11	29 7	4 14	— 7	— —	— —
	<i>A. letifer</i>	DDT BHC	105	36 11	32 2	— —	1 —	6 —	1 —
	<i>A. umbrosus</i>	DDT BHC	39	38 8	69 1	— —	24 —	11 —	8 —
Dead after 24 hr.	<i>A. barbirostris</i>	DDT BHC	21 22	67 11	13 7	0 10	— 1	— —	— —
	<i>A. letifer</i>	DDT BHC	17	18 11	13 2	— —	0 —	3 —	0 —
	<i>A. umbrosus</i>	DDT BHC	6	34 8	62 1	— —	11 —	7 —	6 —
Blood-fed	<i>A. barbirostris</i>	DDT BHC	132 76	64 7	21 3	4 11	— 6	— —	— —
	<i>A. letifer</i>	DDT BHC	100	26 8	26 2	— —	0 —	1 —	1 —
	<i>A. umbrosus</i>	DDT BHC	22	14 1	18 0	— —	17 —	6 —	5 —
Blood-fed in window trap	<i>A. barbirostris</i>	DDT BHC	110 64	31 6	13 3	4 10	— 3	— —	— —
	<i>A. letifer</i>	DDT BHC	90	26 6	24 2	— —	0 —	1 —	1 —
	<i>A. umbrosus</i>	DDT BHC	17	14 1	17 0	— —	17 —	6 —	4 —
Total in window trap	<i>A. barbirostris</i>	DDT BHC	121 69	51 10	18 6	4 12	— 3	— —	— —
	<i>A. letifer</i>	DDT BHC	95	36 9	30 2	— —	1 —	6 —	1 —
	<i>A. umbrosus</i>	DDT BHC	29	34 7	68 1	— —	24 —	11 —	7 —

TABLE XII.

* Mortality at two different localities (Tampin = T and Selangor coast = S) of *Culex pipiens fatigans* that entered window-trap huts treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

	Insecticide	Before treatment	Weeks after treatment											
			1	2	3	4	1-4	5-8	9-12	13-16	17-20	21-24	25-28	
Total found	DDT	108 478	110 511	— 843	102 1077	653	212 3084	176 1483	415 728	— 577	— —	— —	— —	
	BHC	235 722	88 473	67 375	149 302	425 200	729 1350	1479 2352	877 1242	268 —	— —	— —	— —	
	Dieldrin	46 360	1 143	5 320	3 152	7 184	16 799	38 511	302 798	651 312	193 412	37 —	18 —	
Found dead	DDT	5 4	26 97	— 30	4 143	— 29	30 299	6 108	23 39	— 14	— —	— —	— —	
	BHC	2 36	85 463	66 212	123 52	346 41	620 768	565 216	148 148	31 —	— —	— —	— —	
	Dieldrin	0 11	1 127	5 278	1 122	0 169	7 696	25 270	23 70	53 9	15 22	3 —	0 —	
Found dead in hut	DDT	0 4	13 22	— 7	1 25	— 17	14 71	3 31	9 13	— 2	— —	— —	— —	
	BHC	0 11	33 127	19 61	9 42	48 20	109 250	165 63	72 30	15 —	— —	— —	— —	
	Dieldrin	0 11	0 32	0 69	0 16	0 18	0 135	5 72	11 34	21 6	4 18	0 —	0 —	
Dead after 24 hr.	DDT	— —	45 116	— 68	9 173	— 57	54 414	20 138	33 62	— 24	— —	— —	— —	
	BHC	— 63	88 473	67 329	139 114	403 77	697 993	934 369	209 —	42 —	— —	— —	— —	
	Dieldrin	1 22	1 143	5 319	3 150	7 181	16 793	34 413	128 241	278 66	67 55	14 —	4 —	

* Mortality and behaviour of *C. p. fatigans* are recorded in separate Tables (this and the next) because there appear to be differences in mortality between the two localities, not noticed for behaviour. Also it was not possible to keep all the mosquitos 24 hours so the mortality figures

TABLE XIII.

Behaviour of *Culex pipiens fatigans* that entered window-trap huts untreated (control) or treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

	Insect-icide	Before treat-ment	Weeks after treatment						
			1-4	5-8	9-12	13-16	17-20	21-24	25-28
Total found	DDT	638	3787	3011	2169	1993	1551	690	432
	BHC	1007	2079	3831	2119	726	1299	675	351
	Dieldrin	406	815	549	1100	963	605	37	18
	Control	186	798	1591	1174	1046	712	413	331
Blood-fed	DDT	470	1133	1196	992	799	815	369	225
	BHC	714	643	1321	903	467	924	522	273
	Dieldrin	331	360	333	829	676	474	24	12
	Control	157	651	1323	917	731	470	315	278
Blood-fed in window trap	DDT	195	824	681	571	424	332	198	98
	BHC	229	225	475	394	225	247	144	71
	Dieldrin	72	172	151	167	152	81	5	6
	Control	32	124	172	228	221	64	58	51
Total in window trap	DDT	358	3287	2407	1696	1567	1029	507	255
	BHC	507	1547	2856	1440	466	571	275	148
	Dieldrin	141	623	352	413	420	201	16	12
	Control	58	226	415	484	515	292	133	97

Combined results from Tampin and Selangor coast (control at Tampin only).

TABLE XIV.

Behaviour and mortality of *Culex* spp.* that entered window-trap huts treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

	Insect-icide	Before treat-ment	Weeks after treatment				
			1-4	5-8	9-12	13-16	17-20
Total found	DDT	154	268	86	—	—	—
	BHC	96	78	4	—	—	—
	Dieldrin	92	78	116	130	72	34
Dead after 24 hr.	DDT	26	88	18	—	—	—
	BHC	42	76	0	—	—	—
	Dieldrin	9	64	77	9	9	3
Blood-fed	DDT	130	61	22	—	—	—
	BHC	20	24	0	—	—	—
	Dieldrin	65	63	58	104	59	24
Blood-fed in window trap	DDT	109	57	19	—	—	—
	BHC	17	7	0	—	—	—
	Dieldrin	43	56	48	89	46	18
Total in window trap	DDT	129	252	81	—	—	—
	BHC	85	42	4	—	—	—
	Dieldrin	74	70	90	111	51	28

* The species were *C. vishnui*, *C. gelidus* and *C. sitiens*, of which the first was the commonest.

TABLE XV.

Behaviour and mortality of *Mansonia* spp.* that entered window-trap huts treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

	Insect-icide	Before treat-ment	Weeks after treatment					
			1-4	5-8	9-12	13-16	17-20	21-24
Total found	DDT	419	198	81	51	145	80	23
	BHC	35	58	10	3	4	—	—
	Dieldrin	7	36	38	64	38	27	—
Dead after 24 hr.	DDT	72	148	52	27	66	38	7
	BHC	9	56	8	1	0	—	—
	Dieldrin	1	36	36	23	15	6	—
Blood-fed	DDT	239	76	32	25	73	50	12
	BHC	31	31	7	3	2	—	—
	Dieldrin	7	33	28	54	36	27	—
Blood-fed in window trap	DDT	184	66	24	17	56	46	12
	BHC	12	23	4	0	1	—	—
	Dieldrin	4	25	19	31	15	13	—
Total in window trap	DDT	319	169	66	34	120	76	23
	BHC	15	39	4	0	2	—	—
	Dieldrin	4	28	28	38	16	13	—

* The species were principally *M. longipalpis* and *M. uniformis*.

TABLE XVI.

Behaviour and mortality of *Aedes albopictus* and *Aë. butleri* that entered window-trap huts treated with 200 mg. DDT, 40 mg. γ BHC or 40 mg. dieldrin per sq. ft.

	Species	Insect-icide	Before treat-ment	Weeks after treatment				
				1-4	5-8	9-12	13-16	17-20
Total found	<i>Aë. albopictus</i>	DDT	19	39	43	11	—	—
		BHC	36	33	24	17	8	—
	<i>Aë. butleri</i>	DDT	46	48	54	29	—	—
Dead after 24 hr.	<i>Aë. albopictus</i>	BHC	24	14	15	7	5	—
		Dieldrin	13	47	54	99	42	12
	<i>Aë. butleri</i>	DDT	4	34	14	4	—	—
Blood-fed	<i>Aë. albopictus</i>	BHC	8	12	15	7	4	—
		Dieldrin	8	44	45	52	26	7
	<i>Aë. butleri</i>	DDT	4	34	14	4	—	—
Blood-fed in window trap	<i>Aë. albopictus</i>	BHC	17	22	15	7	—	—
		Dieldrin	28	24	17	15	7	—
	<i>Aë. butleri</i>	DDT	33	21	34	16	—	—
Total in window trap	<i>Aë. albopictus</i>	BHC	15	9	12	5	1	—
		Dieldrin	9	37	39	79	29	12
	<i>Aë. butleri</i>	DDT	22	13	29	12	—	—
Total in window trap	<i>Aë. albopictus</i>	BHC	10	7	10	5	1	—
		Dieldrin	4	28	27	44	19	9
	<i>Aë. butleri</i>	DDT	29	22	40	21	—	—
Total in window trap	<i>Aë. albopictus</i>	BHC	15	35	42	7	—	—
		Dieldrin	27	29	20	12	7	—
	<i>Aë. butleri</i>	DDT	29	22	40	21	—	—
Total in window trap	<i>Aë. albopictus</i>	BHC	16	10	12	7	2	—
		Dieldrin	6	34	39	62	27	9

DELAYED OVIPOSITION IN THE SHEEP BLOWFLY, *LUCILIA SERICATA* (MG.).

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Development of the female reproductive organs in the sheep blowfly (*Lucilia sericata* (Mg.)) has been shown to be dependent upon an adequate diet which, under laboratory conditions, can be obtained from liver, sugar and water (Cousin, 1932; Mackerras, 1933). The latter author has further shown that even though the protein, so necessary for egg production, be withheld until ten days after the emergence, fertile eggs are still laid three days later providing fresh supplies of liver are available.

Under field conditions it seems highly probable that not only may there be some delay between emergence and the first protein feed but also between egg maturation and oviposition. This would be due in part to the lack of suitable substances on which to lay and also to adverse weather immobilising the flies. It seemed worth while, therefore, to test the ability of *L. sericata* to retain ripe eggs past the usual time of oviposition.

Methods.

The flies used were from a stock culture which had been maintained for two years in the Department of Agricultural Zoology. A series of 16 muslin cages, $7\frac{1}{2}$ " \times $7\frac{1}{2}$ " \times 15", were used in a constant temperature and humidity cabinet maintained at $25^{\circ}\text{C.} \pm 2^{\circ}\text{C.}$ and 66.5 ± 4.5 per cent. R.H. with overhead lighting given for 12 hours each day by two 100-watt bulbs, placed 14" from the tops of the cages. On the day of emergence, twenty five flies of each sex were placed in each of the 16 cages, together with water, sugar, and a small cube of liver. It is reasonable to suppose that by the fifth day all the female flies would have fed and that the eggs in those which did so on the first and second day would be almost ripe. On the fifth day, the meat was removed from all cages except the controls and then withheld for periods varying from 6 to 24 days before being finally replaced. The meat was then removed daily, placed in an incubator and at the end of 24 hours the larvae and unhatched eggs were counted. It was found impossible to determine the number of egg batches on so small a piece of meat in order to obtain the number of flies ovipositing. The position of the cages within the incubator was altered daily in order to eliminate any possible positional effect.

Results.

Conditions for breeding were considered satisfactory since over 90 per cent. of all eggs laid gave rise to larvae and, at the end of 34 days, 50 per cent. of the controls were still alive.

The results, expressed as mean number of eggs per female fly, are shown in Table I. An analysis of variance of the daily egg production in the three control cages (nos. 1-3) showed that the variation between the cage averages is commensurate with the population variance as indicated by the variation between days within cages.

Cage no.	No. of days meat withheld	Age of flies in days															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	0	Diet of meat, sugar, and water.					23 34	23 23	23 41	23 82	23 37	23 22	23 57	23 82	23 33	23 33	
2	0					22 26	22 49	22 28	22 34	21 35	20 51	20 38	20 62	20 15	20 68	20 68	
3	0								23 10	23 28	23 4	23 49	23 46	23 23	23 12	23 42	
4	6	Diet up to the end of the 5th day consists of meat, sugar and water														25 88	25 18
5	8																25 75
6	10																
7	10																
8	10																
9	10																
10	13																
11	13																
12	14																
13	21																
14	21																
15	24																
16	24																

* Only occasion when eggs

Source of variance	Amount of variance	Degrees of freedom	Estimate of variance
Between cages ..	3174.1	2	1587.05
Between days ..	44478.7	78	570.24
Total	47652.8	80	

$$F = \frac{1587.05}{570.24} = 2.78 \text{ (Value for variance ratio at 5\% level = 3.15).}$$

The first eggs appeared on the 5th, 6th and 7th day, respectively, in these three cages but, apart from this small difference, the general trend in egg production was similar in all three controls, namely rising to a maximum in the second and third weeks and showing a drop in the fourth week. When the data were divided up into 3 nine-day periods, analysis showed this peak was not significant at the 5 per cent. level.

In the experimental cages nos. 4 to 16, meat, sugar and water were provided for the first five days and thereafter the meat was withheld for periods from 6 to 24 days. Under these conditions there was no evidence to show that *L. sericata* would shed mature eggs in the absence of a suitable material for oviposition, for throughout the experiment there were only three occasions when eggs were not laid in contact with the meat. On two of these occasions the batches were laid under the dish containing the meat and the third time related to cage no. 7 where a dozen eggs (average = $\frac{1}{2}$) were laid a short time before replacement of the meat. It is possibly significant that this last batch was deposited on the netting floor where there was an old blood stain. Retention of eggs is possible then, providing there is no suitable oviposition site, for as long as 24 days.

When the effect of this delayed oviposition is examined in relation to the mean daily egg production per female, it will be noted that so long as the period of egg retention is no more than ten days then no serious effects result. The means of the first 3-day, 4-day, 5-day period after replacement of the meat in the separate cages nos. 4 to 9 showed no significant difference at the 5 per cent. level when compared with the mean of the controls. From Table I it does appear, however, that the figures on the first day may be a little greater than the controls due possibly to all the flies tending to come "on lay" at once.

When the meat is withheld for longer periods, there is a sharp drop in egg production even to the extent of there being no eggs deposited for the first two days (see cages 11, 12, 14 and 15). That a few flies are capable of retaining their eggs ready for quick oviposition on the presentation of a suitable substrate, is shown by cage no. 16, when even after 24 days without meat 570 eggs, probably representing the product of 2 or 3 flies, were laid within 24 hours of the replacement of the meat. Recovery of the normal rate of egg production is attained usually four or five days after replacement of the meat. Although cages nos. 14, 15 and 16 show smaller numbers alive at the end of the experiment than do the controls, the death-rate in most of the experimental insects did not appear unduly affected.

Discussion.

It should be noted that Cousin (1932) and Evans (1936) suggest that cages should have a volume of at least $\frac{1}{3}$ cubic metre, otherwise copulation is interfered with and only sterile eggs are laid. The individual cages used in this experiment

were considerably smaller than this suggested minimum size ($\frac{1}{80}$ cu. metre) and yet there appeared to be no interference with normal reproduction. It must be remembered, however, that the cages used were all stacked upright and although not actually in contact, it is conceivable that flies in neighbouring cages affected one another. If the crucial factors are total population and density it may well be that a number of small cages so arranged provides a similar environment to one large cage.

The consistently lower rate of egg production in control cage no. 3 in relation to the other control cages is difficult to understand since the death-rate is similar in all three cages (see Table I). Mackerras (1933), Ulyett (1950) and Hobart (unpublished) have shown that the number of eggs maturing at one time in the ovaries is strictly proportional to the size of the individual and measurement showed that there was no significant size difference between these three groups of flies. It is possible that the time between successive ovipositions may have been rather longer on average in cage no. 3. The general trend of egg production, however, agrees very well with the published figures of egg production for individual flies given by Salt (1932) and Mackerras (1933) where it can be seen that, as the fly ages, the time interval between successive batches of eggs increases.

The data of both Cousin (1932) and Mackerras (1933) suggest that the powers of egg retention are slight since if no meat is available the flies will oviposit on fruit, especially slit dates. The evidence from Hobson (1938) conforms in the main with my own experience in that he noted females, if kept without meat, occasionally laid "on the sides of the cage, on wet cotton-wool, or on sugar, particularly if this has started to ferment". He further suggests that there might be some difference between laboratory-bred and wild flies. It would appear that the former show some ability to retain their eggs since he noted the readiness of flies to oviposit "was always increased by leaving the flies for several days after removing the meat", and yet he remarks on the difficulty experienced in transporting gravid flies to the laboratory from the field, since many oviposited before being subjected to experimentation.

The results clearly indicate that under the experimental conditions *L. sericata* can retain eggs without harm up to periods of ten days past the normal time of oviposition. If the period is extended, then the average egg production, on replacement of meat, is lowered although some individual flies can retain their ripe eggs unharmed for as long as 24 days. This lowered egg production can best be accounted for by individual flies "going off lay", possibly due to re-absorption of the oöcytes; this phenomenon was noted by Wigglesworth (1936) in starved *Rhodnius* females. Flanders (1942) has shown that some parasitic Hymenoptera can maintain their reproductive capacity during unfavourable conditions by storage after ovulation if the eggs are of the "hydropic type". If they are of the "anhydropic type", i.e., with a fully sufficient quantity of reserves at the time of laying, the parasite, in order to delay oviposition, is dependent on a cyclical re-absorption of oöcytes. There is no evidence to suggest that such a cyclical re-absorption takes place in *L. sericata* but it may well be that after meat has been withheld for some time the food reserves of the adults become depleted and that further supplies for body maintenance are obtained by re-absorption of the matured oöcytes.

It is of interest that laboratory-bred *L. sericata* can delay oviposition for such periods in view of the fact that it needs at least one meat meal to initiate egg development, possibly a second to complete development (Hobson, 1938) and then further sources of meat for oviposition and further feeding. The availability of carrion clearly must vary but if the flies experience a delay of several days in seeking out these sources, either through scarcity of dead animals or unfavourable weather conditions, then reproduction should not be impaired.

Summary.

Lucilia sericata (Mg.) has been bred successfully in small cages having a volume of about $\frac{1}{100}$ cubic metre.

Female flies that contain ripe eggs, if given only sugar and water, will withhold their eggs for periods up to 24 days. There appears to be no decrease in the numbers of eggs laid or in the percentage of young larvae hatched, providing the delay in oviposition is not longer than ten days. If the meat is withheld for longer periods then there is a reduction in the daily egg production.

References.

- COUSIN, G. (1932). Étude expérimentale de la diapause des insectes.—Bull. biol. Belg., Suppl. **15**, pp. 1–341.
- EVANS, A. C. (1936). The physiology of the Sheep Blow-fly, *Lucilia sericata* Meig. (Diptera).—Trans. R. ent. Soc. Lond., **83**, pp. 363–377.
- FLANDERS, S. E. (1942). Oösorption and ovulation in relation to oviposition in the parasitic Hymenoptera.—Ann. ent. Soc. Amer., **35**, pp. 251–266.
- HOBSON, R. P. (1938). Sheep Blow-fly investigations. VII. Observations on the development of eggs and oviposition in the Sheep Blow-fly, *Lucilia sericata* Mg.—Ann. appl. Biol., **25**, pp. 573–582.
- MACKERRAS, M. J. (1933). Observations on the life-histories, nutritional requirements and fecundity of blowflies.—Bull. ent. Res., **24**, pp. 353–362.
- SALT, G. (1932). The natural control of the Sheep Blowfly, *Lucilia sericata*, Meigen.—Bull. ent. Res., **23**, pp. 235–245.
- ULLYETT, G. C. (1950). Competition for food and allied phenomena in Sheep blowfly populations.—Phil. Trans., (B) **234**, pp. 77–174.
- WIGGLESWORTH, V. B. (1936). The function of the corpus allatum in the growth and reproduction of *Rhodnius prolixus* (Hemiptera).—Quart. J. micr. Sci., **79**, pp. 91–121.
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THE ANOPHELINE MOSQUITOS OF THE SUDAN.

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The known distribution of the Anophelini of the Sudan is shown in figs. 2 to 14, in which the species are arranged as in the text of De Meillon's book (1947). The place names given in the distribution lists, however, are only those that are additional to the records given by Abbott (1948), De Meillon (1947), Evans (1938) and Lewis (1945). Place names additional to those given by Lewis (1945) and in papers referred to by him are included in fig. 1. Initials in brackets are those of collectors whose names are shown in the acknowledgements section.

The Sudan very slightly overlaps the Palaearctic Region and is not far from the Oriental Region, so that, to be certain of identifying Anophelines in the north-eastern Sudan, it is desirable to consider some of the species of three regions, as has been done by Macan (1942). For this reason, and to illustrate some general features of distribution, figs. 15 and 16 show the distribution of certain species in three countries adjoining the Sudan. The data were obtained from sources mentioned by Lewis (1955) and from Baz (1950), Barber & Rice (1937), de Burca & Shah (1943), De Meillon (1947), Farid (1940), Khalil (1936), Lega, Raffaele & Canalis (1937), Madwar (1936), Madwar & el Shawarby (A short report on the eradication of *Anopheles sergenti* from the oases in Egypt 1946-1948. World Hlth Org. Mal/39, unpublished, 1950), Mara (1950), American Geographical Society (1951) and Shousha (1948).

The distribution of *A. gambiae* Giles in the Wadi Halfa area is considered at some length because its northern limit is in this region, and it is important to prevent the species from spreading northwards in aircraft (Findlay, 1946) or in other ways. The Anophelines of the coast are briefly discussed, and other areas, in which Anophelines are not the only important mosquitos, will be included in another paper.

Several instances of Anophelines (*A. nili* (Theo.), *A. gambiae* and *A. pharoensis* Theo.) biting out-of-doors by day are mentioned below. These are apparently exceptions to the rule and may be somewhat comparable to attacks on man by plant-sucking bugs which are probably induced to bite by the dry climate of the Sudan.

NOTES ON THE SPECIES.

Anopheles (Anopheles) coustani Laveran.

In specimens from various places the third hind tarsal segment is pale, as in some West African specimens (De Meillon, 1947).

Additional records are from Abu Zor, Bandula, Kagelu, Peili (*P.H.A.*), Li Rangu (*P.H.A.*), Li Yubo, Tembura and Wau (*P.H.A.*). Adults have been found in trains at Aroma and Gedaref. *A. coustani* has been reported from the Aswan reservoir by the Egyptian Ministry of Health.

Anopheles (Anopheles) coustani var. **ziemanni** Grünberg.

The many new localities may be noted by reference to fig. 2.

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Anopheles (Anopheles) obscurus (Grünberg).

There are no new records.

Anopheles (Anopheles) symesi Edwards.

There are no new records.

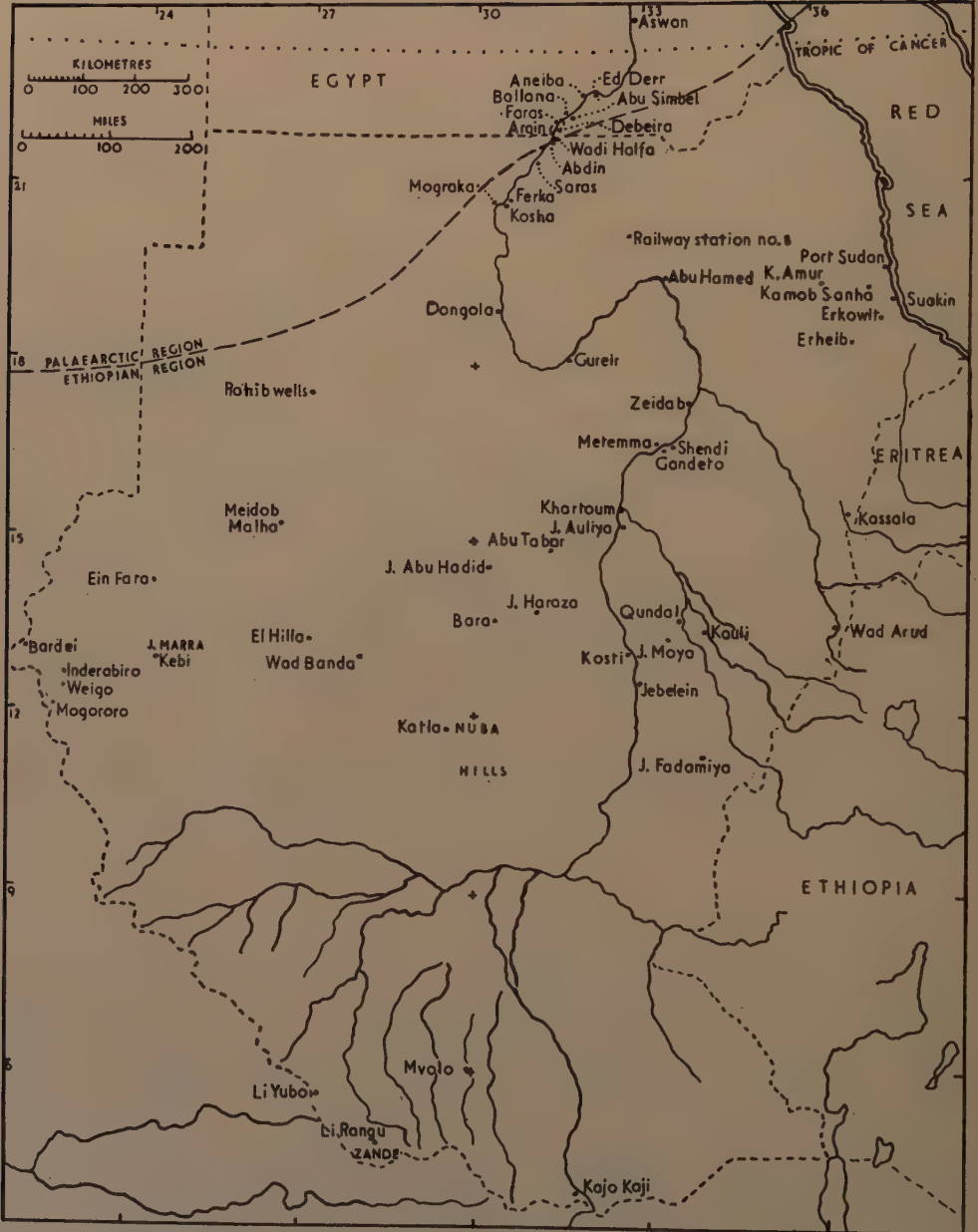


Fig. 1.—Map of the Sudan showing some places mentioned in the text, including those not shown by Lewis (1955) or in previous papers.

Anopheles (Anopheles) implexus (Theobald).

This species is known from Lotti, Maridi and Yei.

Anopheles (Myzomyia) nili (Theobald).

Larvae from Juba, Kuru and Torit have been examined and their fully developed palmate hairs found to differ from the kind figured by De Meillon (1947, plate 20, h) but to be rather like his figure of the palmate hair of the first abdominal segment. The filament of each leaflet is simple and on either side of the base of the filament the blade usually ends in a single long blunt projection.

Localities include Adok, Jebel Ahmed Agha (the type locality), Akobo (J.F.E.B.), Beika, Bor, R. Bussere, Gemmeiza, Jebelein, Jokau (J.F.E.B.), Kuru, Lado, Li Yubo, Khor Machar (J.F.E.B.), Maridi, Meshra er Req, Mvolo, Nasir, R. Pibor, Raga, Senango Faki, Sennar, Shambe, middle of R. Sobat, Torit, Khor Yabus and Yei. Theobald (1906) reported that many were found on the Blue Nile.

De Meillon (1947) points out that the behaviour of *A. nili* varies in different parts of Africa and that in some areas it may be an important vector of malaria. This species has not been specially studied in the Sudan, but field notes give some information about it. It appears to bite man readily and to rest in houses to some extent but in most of its known localities it does not seem to be abundant. Each of the following notes refers to a few individuals, except at Nasir and K. Yabus.

Jebelein, Lul, Raga, Shabak, Wau and Zuleita: bit out-of-doors in evening. Senango Faki: one bit at 1100 hr. in September in bright sunlight on a bridge over an open river. K. Yabus: 290 caught with 40 *A. gambiae* biting outside rest-house in evening, 7.i.47, the nearest village some distance away. Gemmeiza and Mvolo: bit in evening in steamer and house respectively. Mvolo and Nzara: in houses by day (few houses have been examined in localities of *A. nili*). Juba, Kosti, Lado, Malakal, L. No and Shambe: in (screened) steamers by day. R.



Fig. 2.

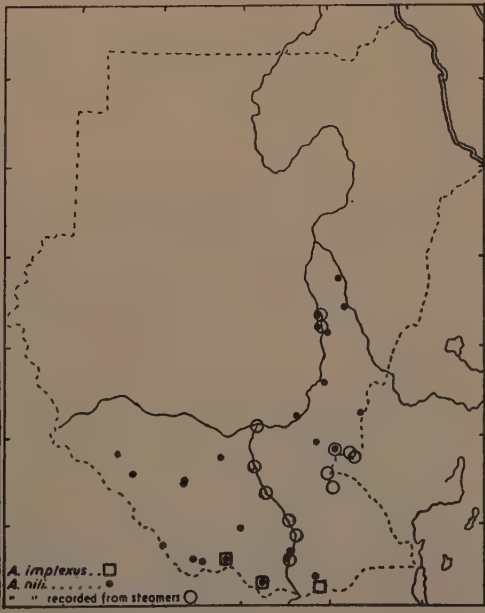


Fig. 3.

Bussere, Maingbara, Torit and Yei: in mosquito net. Nasir: reported by Wenyon (1908) to be common.

Anopheles (Myzomyia) rhodesiensis Theobald.

A. rupicolus Lewis is here treated provisionally as a synonym of *A. rhodesiensis*, of which it may be regarded as a local colour form. "Form *rupicolus*" is so different from typical *A. rhodesiensis* that it has been described on three occasions as a new species, *rupicolus* Lewis, *aegypti* Salem and *dthalisimilis* Corradetti. De Meillon later (1947) questioned whether the two forms were distinct, in view of the similarity of the larvae and pupae, and also of the adults apart from *rupicolus* being paler and its palps and wings having less distinct pale markings.

The following notes on specimens from different localities show the varying nature of the wing markings. The letters *b* to *e* indicate pale costal spots as in Evans's figure (1938, p. 17). Unless otherwise indicated, the brown costal scales (B.S.) are pale brown and the pale spots, which are seldom very clearly marked, are faint or absent. Owing to the occurrence of intermediates between faint and clear spots, the numbers of specimens indicating these features are approximate.

Malha: 1 ♀ examined, *c* clear; 4 ♂♂. Erkowit: 1 ♀ with *c*. Port Sudan: 1 ♂ with *c* and *d* clear. Kassala: 12 ♀♀, 4 with *c*; 6 ♂♂, 1 with clear *c* and *d*. J. Moya: 54 ♀♀, 17 with *c*, usually faint, tending to be repeated on vein 1, 2 with *c* and *d*; 20 ♂♂, 2 with *c* and *d*. Here and at Kassala some of the plain wings have traces of *c*. Nuba Hills, Heiban: 1 ♂ with *c* and *d*. Nuba Hills, Kauda: 1 ♀, B.S. rather dark, with *b*, *c* and *d*. Nuba Hills, Talodi: 1 ♀ with *b*, *c* and *d* (determined by Edwards in 1932 as *A. rhodesiensis*); 1 ♂ with *c*. Mvolo: 2 ♀♀, B.S. dark, 1 with *b*, *c* and *d*, *b* only on vein 1, 1 with distinct *b*, *c* and *d*, all repeated on vein 1. Kajo Kaji: 1 ♂ with B.S. dark and with *b*, *c*, *d* and *e*, all repeated on vein 1.

Material has also been examined from Eritrea.

Eritrea, various places: 3 ♀♀, 2 with rather dark B.S., 1 with *c* fairly clear, 1 with *c* and *d* fairly clear; 1 ♂ with *c* and *d*. Eritrea, Chenafena (near R. Mareb 60 km. from Asmara, 1,631 metres high): 3 ♀♀ with B.S. rather dark, 1 with *c*, 1 with *c* and *d* clear and *e* faint (*D. Verdecchi*).

In form *rupicolus* on or near isolated rocky hills at Kassala and J. Moya the brown wing scales are rather pale and the pale spots are absent or scarcely perceptible in most specimens, and are represented by *c* in some and by *c* and *d* in a few. In more hilly areas in the northern Sudan there seems to be a tendency for brown scales to be rather dark and for more pale spots to be present.

The few available specimens from the southern Sudan and possibly some specimens from Eritrea (de Burca & Shah, 1943) and the Yemen (Knight, 1953) represent a darker form, with more spots and with a trace of palpal markings, which approaches typical *A. rhodesiensis*.

The distribution of *A. rhodesiensis* is somewhat discontinuous in the Sudan, but perhaps every gradation may exist in Ethiopia between the different forms. It should be noted however that, in addition to the characters of form *rupicolus* given by De Meillon and referred to above, it shows a marked tendency for the number of the pale wing spots to be reduced.

Three egg shells from J. Moya, almost certainly of this species, have been examined. They were not curved at the ends as in the specimen figured by Salem (1938), there were 16 to 19 float ridges, and the frill was not continuous above the floats.

Additional localities, apart from those mentioned above, are Kadugli, Kologi, Kororak, Kurmuk, Masakin, Murukwa, Suni (one larva), Tubor and Yei. Specimens are also available (*M.A.F.*) from Mona (a suburb of Mecca, Arabia, found with larvae probably of *C. sinaiticus* Kirkpatrick) and Ain Abrak (S.-E. of

Aswan, Egypt, larvae (*M.A.F.*), and from the Eritrean localities, Barentu, Keren, Mai Eta, Nacfa and Tessenei.

Anopheles (*Myzomyia*) *dthali* Patton.

New localities are K. Amur, K. Arbaat, Faras, Gebeit and Kamob Sanha.

A. dthali has only once been found at Faras (four larvae, *S.M.M.*, 30.xii.45). It appears to have spread from Egypt since Shousha (1948) reported a few from Assiut in September 1945 and from Nubia in October.

In the Red Sea coastal area it breeds in various types of water, including bare sandy pools where one would expect to find *A. gambiae*.



Fig. 4.

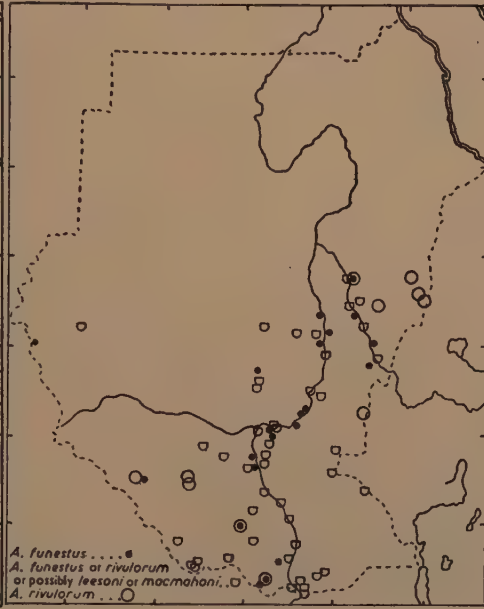


Fig. 5.

Anopheles (*Myzomyia*) *funestus* Giles.

Additional localities are Adok, J. Bagis, Danagla, Fangak, Fashoda, Kagelu, Keri Kera, Kodok, Kosti, Kuru, Mogororo area (*A.T.*), Renk, Thar Jath, Wath Wang Kech and Yei.

A number of localities of either *A. funestus* or *A. rivulorum* Leeson or similar species are shown in fig. 5. These include Kalokitting and Rahad.

A few *A. funestus* have been seen to bite man indoors by day near Lake Jur.

Anopheles (*Myzomyia*) *rivulorum* Leeson.

Additional localities are Deim Zubeir (*P.H.A.*), Mvolo; Peili (*P.H.A.*), K. Yabus and Yei.

Many larvae, possibly of this species, have been found among water-lily leaves in a riverain swamp at Kauli (*J.B.*). It has been found breeding at Hawata in December in a year when the R. Rahad was at the level of sedge and gravel.

A few observations have been made at Hawata in December on the adults of this species which is not generally regarded as a house frequenter. A few were found biting out-of-doors, but no adults were seen in houses near the riverain breeding places. A prolonged search among vegetation and in mud cracks near

the river revealed a male and a female in the cracks. Bred females kept in tubes bit readily, on the day of emergence but not subsequently. Many adults of this species have been found in a cave at Wad Arud.

Anopheles (Myzomyia) leesonii Evans.

Single larvae apparently of this species have been found at Maridi and Niertete. It and *A. rivulorum* occur in Uganda near the Sudan border (Leeson, 1937).

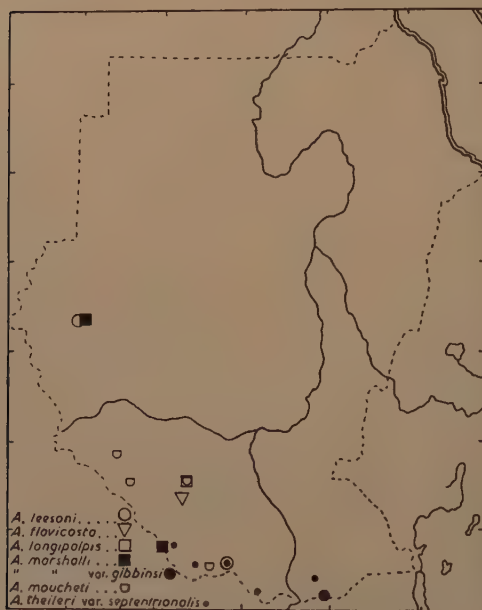


Fig. 6.

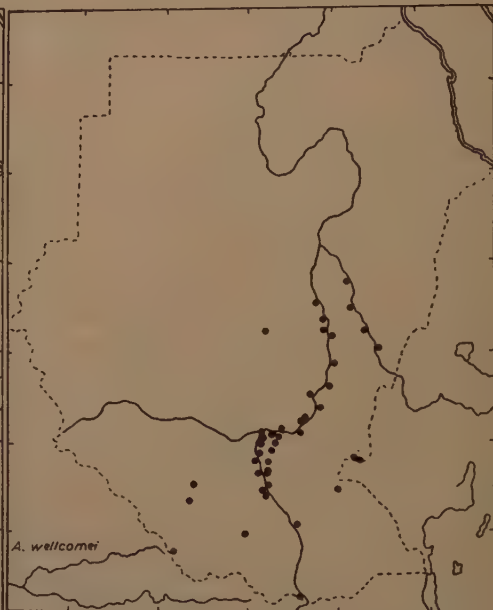


Fig. 7.

Anopheles (Myzomyia) flavicosta Edwards.

Two females of this species, hitherto only known from West Africa, have been obtained biting at Peili (*P.H.A.*).

Anopheles (Myzomyia) longipalpis (Theobald).

A larva has been found at Wau.

Anopheles (Myzomyia) marshallii (Theobald).

One larva has been found at Li Yubo (*P.H.A.*) and many on J. Marra, at Kelling, Kronga (*P.H.A.*) and Suni.

Anopheles (Myzomyia) marshallii var. *gibbinsi* Evans.

Adults have been found at Lotti (*M.S.*).

Anopheles (Myzomyia) moucheti Evans.

This species occurs at Deim Zubeir and between Maridi and Yambio (*P.H.A.*), and at Raga and near Wau (*P.H.A.*).

Anopheles (Myzomyia) theileri var. **septentrionalis** Evans.

Additional localities are K. Awe, Li Rangu, Maridi and Ndingbo.

Anopheles (Myzomyia) wellcomei Theobald.

In a few females from Kosti the third palpal segment is mainly dark.

New records are from Adok, J. Ahmed Agha, Buffalo Cape, Fangak, Lake Fasheir, Fashoda, K. Gurr, Bahr el Jebel km. 321, Jokau, L. Jur, Kaka, Lul, K. Machar (*J.F.E.B.*), Malakal, Panamtin, Peili (*P.H.A.*), R. Pibor, Renk, Sennar, Shukoli, Thar Jath, Tonga, Wath Wang Kech, Bahr ez Zaraf km. 46, 121, 190.

Anopheles (Myzomyia) demeilloni Evans.

This species occurs at Katire and Nagishot. A large worm, probably *Mermis* sp., was found in one larva from Nagishot.

Anopheles (Myzomyia) garnhami Edwards.

This species occurs at Gilo, Katire and Nagishot.



Fig. 8.



Fig. 9.

Anopheles (Myzomyia) macmahoni Evans.

In larvae from near Suni there is a dark patch on the anterior part of the fronto-clypeus, and in some specimens the head is nearly all dark except round the eyes, and the antennae are very dark.

New records are from Mvolo and the Suni area.

Anopheles (Myzomyia) gambiae Giles.

In some larvae of *A. gambiae* and *A. pharoensis* from the plains of Darfur the upper part of the head is entirely pale.

Females with four-banded palps have been found at Kagelu.

A. gambiae is widely distributed in the Sudan as far north as about 14°. Beyond this it occurs mainly along the Nile as far as Ferka, and on other rivers, in irrigated areas and on or near certain hills. Of the many localities shown in fig. 9 the following may be mentioned: Abu Tabar, J. Abu Hadid, Ein Fara, Erheib, Erkowit, J. Haraza (a range of hills with permanent water-holes, MacMichael, 1927), Kamob Sanha and Port Sudan.

The incidence of this species towards the northern limit of its range, and records of abnormal behaviour, are discussed in detail on pp. 486-489.

Anopheles (Myzomyia) cinereus Theobald.

Larvae from J. Marra are rather dark, especially in the third stage, and in the palp of the female the terminal pale band is reduced or absent.



Fig. 10.



Fig. 11.

New records are from Daia, Guldo, Kalokitting, Kenunbuna, Kebi, Kelling, Nyertete, So'unga and Wadi Turo, all on or near J. Marra. The species occurs at the foot of the mountain as well as on the upper slopes where Abbott (1948) found it.

Several males, of which six were captured together with a female *C. theileri* Theo., were seen swarming over a table on a terrace out-of-doors at Suni (J. Marra) at 1815 hr. (after sunset) on 8th January 1954.

Anopheles (Myzomyia) turkhudi Liston.

Additional localities are Gebeit Gold Mine and Port Sudan.

A female has been seen biting man in a house at Erkowit at 2000 hr. in August (W.R.).

Anopheles (Myzomyia) multicolor Cambouliu.

There are no new records.

Anopheles (Myzomyia) rufipes (Gough).

Some variations seen in this species are as follows:

Palp of ♀: rarely with dark tip (Rahad). *Wing*: length of costal pale spots very variable; pale interruptions of second main dark area of vein 1 variable, sometimes one absent or one or the other joined to the nearest pale spot. *Hind tarsus*: segment III often with pale basal ring, more than half of segment white in some specimens from K. el Gora, Kosti and Sennar; segment IV with some dark scales or a black band in occasional specimens (Kosti and Meidob); segment V sometimes with grey or black tip or more than the distal half black (El Amira, Kosti and Umm Ruwaba).

Of the known localities of this species (fig. 11) the most northerly ones away from the Nile are Meidob (10 miles south, 5.ix.34, R.C.M.-D.) and Kassala.

This species usually breeds among vegetation in swamps but larvae have been found in small seepage pools on the bank of the Nile at Qundal and Wad Medani in the dry season, in May, when the usual breeding places were dry.

The house-haunting habits of the adults are mentioned below in the section on malaria.

Anopheles (Myzomyia) rufipes var. **ingrami** Edwards.

In some specimens there is a narrow dark band near the base of the third hind tarsal segment (Kebi), and in some a quarter of the segment is dark (El Amira). In a specimen from Li Yubo there are some dark scales on the fifth segment.

The variety seems to be commoner in the south than the north. A female, probably about to bite, has been found on man.

Anopheles (Myzomyia) pretoriensis (Theobald).

In some specimens from Heiban the palp of the female has a dark tip, and in some there are four pale bands and the distal dark band may be broad.



Fig. 12.



Fig. 13.

Additional localities are Bongo, Dilling, Ein Fara, J. Fadamiya (*O.I.M.*), Katla, Kebi, Kelling, Kenunbuna, Kurmuk, Kuru, El Liri, Li Yubo, Malha (one larva), Sheikh Karim and K. Shumam. This species is normally confined to the neighbourhood of rocky hills and the Wad Medani record (Lewis, 1945, p. 6) is probably due to a chance introduction.

Anopheles (*Myzomyia*) *maculipalpis* (Giles).

Additional localities are Li Rangu, Miri, Wau (*P.H.A.*), Yambio and Yei.

Anopheles (*Myzomyia*) *pharoensis* Theobald.

De Meillon (1949) has described variations in the larval palmate hairs. In most Sudan specimens examined the well-developed hairs are of the narrow type with few serrations and a long filament. The integument of the mesonotum is dark in a few adults from various places.

Among the numerous localities of this species (fig. 13) some of the northern ones are Abka (probably an occasional visitor from Egypt here and at Faras), Abu Tabar (*W.R.*), Bardei, Faras, Geneina, J. el Hilla, Matemma, Rahib wells ($17^{\circ} 32' N.$, $27^{\circ} 03' E.$, September 1951, *J.K.M.T.*), Wad Banda and Zeidab. Mara (1950) found this species and *A. squamosus* Theo. around Tessenei in Eritrea so they probably sometimes occur in the neighbouring area of Kassala.

Garrett-Jones (1950) has discussed wind-borne flights by this species which can apparently travel up to about 70 km. (45 miles) or possibly more in this way. It exists largely in swampy areas (fig. 13), and its occurrence in some of the north-western localities may be the result of long flights during the rains when the south winds blow. An example of this may be the appearance of *A. pharoensis* at Rahib, where the average rainfall is probably less than 50 mm. A

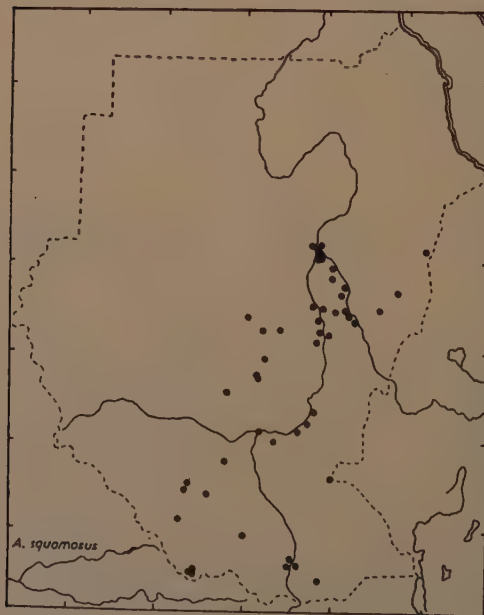


Fig. 14.

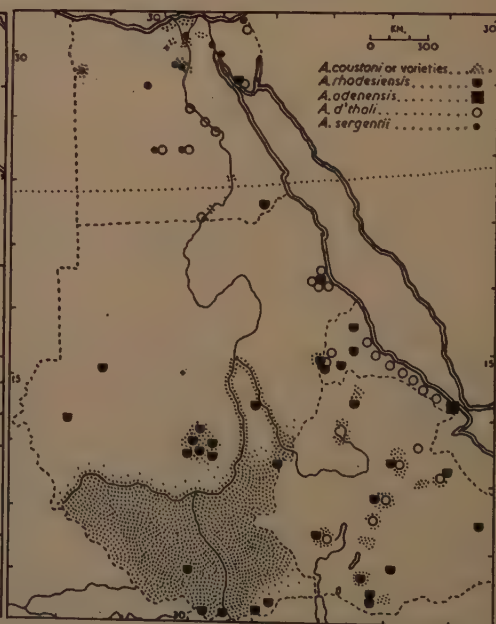


Fig. 15.—Map showing approximately, with some interpolations, the distribution in one or more of four adjacent countries—the Sudan, Egypt, Eritrea and Ethiopia—of four species of *Anopheles*.

dry-season flight was probably responsible for the finding of adults biting in the morning of 18th February 1952—but not the previous evening—at Abu Gidada (*J.K.M.T.*), the site of some wells 28 km. from the White Nile and about 50 km. from the probable breeding area. Most *A. pharoensis* soon disappear from houses on the lower White Nile and are believed to be carried away inland by the wind.

Two females were seen to bite man in a swamp at Kereida in sunshine at 1315 hr. in January, but this is an unusual occurrence. This species has been seen to bite a donkey.

Anopheles (*Myzomyia*) squamosus Theobald.

New records are from Abu Ushar, R. Bussere, Gedaref, Gereif, Gondokoro, Kassala, Keilak, Lado, Li Rangu, Meshra er Req, Munktar, Mvolo, Nzara, El Obeid, Omdurman, Tiptiap, Tonj, Torit, Umm Ruwaba, Umm Sunt, Wad Medani, Wad Shair and Yambio.

A. squamosus occurs mainly near rivers (fig. 14) but on the other hand it is often found breeding in open rain-water floods with some grass but no permanent aquatic vegetation. It is occasionally found biting man out-of-doors at dusk.

GENERAL DISCUSSION ON DISTRIBUTION OF THE SPECIES.

De Meillon (*in* Boyd, 1949) enumerates 69 species of *Anopheles* (excluding *A. rupicolus*) in the Ethiopian Region. A large proportion—28 species and three varieties—occur in the Sudan. The number is high because, although the Sudan

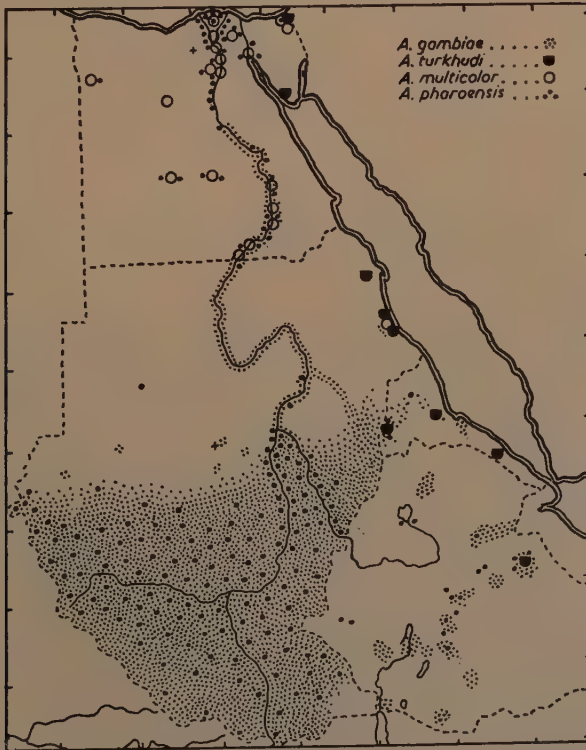


Fig. 16.—Map showing approximately the distribution in one or more of four adjacent countries of four species of *Anopheles*, including the extension into Egypt of *A. gambiae* in 1944.

is mainly desert or rather dry uniform country, some of its marginal areas support some essentially Palaearctic, East African and West African species.

Seven species, *A. coustani*, *A. rhodesiensis*, *A. dthali*, *A. gambiae* (now absent from the Palaearctic Region), *A. turkhudi*, *A. multicolor* and *A. pharoensis*, are, or have recently been, common to the Ethiopian and Palaearctic Regions. They have all been found in the Sudan and all except *A. turkhudi* in Egypt. The Mediterranean species, *A. dthali* and *A. turkhudi*, and *A. multicolor*, do not extend far into the Sudan, and the Palaearctic *A. sergentii* (Theo.) has not been found in this country. *A. dthali* is sometimes found breeding in slightly saline water in Egypt, *A. multicolor* is largely a desert species which can tolerate a high degree of salinity, and *A. sergentii* is a desert form (Boyd, 1949). *A. adenensis* Chr., which is related to an Indian species, has been found on the Red Sea coast in Eritrea.

Three Ethiopian species, *A. coustani*, *A. gambiae* (discussed in detail below) and *A. pharoensis*, have spread into the Palaearctic Region, the first and last of them (figs. 15 & 16) as far as the Nile delta. Owing to the riverain distribution of *A. coustani* and the prevalence of var. *ziemanni* in the Sudan, one would expect this variety to have reached Egypt, rather than var. *tenebrosus* which has been reported from that country. The differences between these varieties are small and the leg markings can vary, and the Egyptian *A. coustani* are separated by a wide gap from the Ethiopian area of the species. It is conceivable that the Egyptian form may have developed, independently, from *A. coustani*, unless var. *tenebrosus* existed in the Sudan when the species reached the Nile delta.

As in other genera of mosquitos, some species are confined to the southern border, and some, such as *A. macmahoni* and particularly *A. cinereus*, are more widespread but show a very discontinuous distribution.

The occurrence of pale forms in dry climates is noticeable among the Anophelines, some or all of the following apparently illustrating this tendency: *A. rhodesiensis* form *rupicolus*, *A. dthali*, *A. wellcomei*, *A. macmahoni*, *A. turkhudi*, *A. multicolor* and *A. pharoensis*. The occurrence of dark larvae of two species on J. Marra has been noted above.

ADDITIONAL NOTES ON *A. gambiae*.

Incidence towards northern Limit of Range.

The Port Sudan-Sinkat area.

Owing to the air and sea communications between Port Sudan and Egypt and other countries, many searches have been made for mosquitos, and many identified in the course of years. *A. dthali* breeds in wadis in the hills where *A. rhodesiensis* and *A. turkhudi* are not uncommon and *A. gambiae* is occasionally found. Around Port Sudan all these species, as well as *A. multicolor*, have been found, *A. dthali* being seen more than the others. In 1931 (Sudan, 1932) the presence of a few Anophelines was attributed to carriage in trains from Kassala. A few specimens of *A. gambiae* have been found by Public Health searchers on trains from Kassala (7.iv.42, 3 ♀♀; 6.xi.42, 1 ♀). The only other record of this species from Port Sudan is of two larvae, found with larvae of *A. dthali*, in a well on 3rd May 1953. The section on malaria, below, contains notes on malaria and *A. dthali* in this area.

Although *A. gambiae* is rare at Port Sudan, presumably owing to the low rainfall of only 99 mm., it is known from Jedda, where malaria has evidently been quite a serious problem (Buxton, 1944).

The area north of Wadi Halfa, extending into Egypt.

In 1942 this important tropical malaria vector of the Ethiopian Region spread northward from the Aswan reservoir area with disastrous results (Busvine, 1948;

Egypt, 1950; Shousha, 1948; Soper, 1948). It eventually reached a point 850 km. down the Nile below Faras and 600 km. inside the Palaearctic Region before it was exterminated in Egypt by 19th February 1945 (Shousha, 1948). Lewis (1944, 1949) recorded the results of surveys and extermination measures in the Wadi Halfa area, and in this and the following sections the northern limit of *A. gambiae* is considered and some events since 1945 are recorded.

Fifteen species of mosquitos are common to Egypt and the Sudan, and several of them are Ethiopian species which have presumably spread along the Nile from one Region to the other during a wetter period than the present one. Several, such as *A. coustani* (fig. 15), have receded from the desert area but *Culex univittatus* Theo. occurs all along the Nile. It seems very probable that long ago *A. gambiae*, which often shares its breeding places with *C. univittatus*, extended further down the river and, as the extreme desert climate developed, receded to a point near the Ethiopian-Palaearctic boundary. In recent centuries, till 1942, its northern limit probably lay between Saras and the Tropic of Cancer, which crosses the northern part of the Aswan reservoir (fig. 1). In this area *A. gambiae* apparently survived the relatively cold winter (with occasional frosts at Wadi Halfa) in certain places where there are long-lasting pools, and its distribution fluctuated from season to season and perhaps from year to year. De Meillon (1949) considers that it passed into Egypt more than once, and it probably existed at Ed Derr (fig. 1) in 1919 (Lewis, 1949; Shousha, 1948). Heavy rains fell there in July (Shousha, 1948) and, later, according to official reports, malaria broke out along about 106 km. of river and there was a high mortality, with the dead lying unburied at Ibrim, opposite Anieba. Afterwards there was a small outbreak at Aswan.

The Nile valley in Egypt has long been recognised as a vulnerable area, subject to the risk of an increase in malaria resulting from the spread of cases or of Anophelines from neighbouring regions. In 1916 a commission was initiated in Cairo to consider the risk from the oases and the canal zone (Egypt, 1919). In 1925, Kirkpatrick thought that *A. gambiae* might occur in south-eastern Egypt (Lewis, 1944), and in 1938 Shousha (1948) foresaw the possible risk of introduction of this species by air. Much of the Egyptian part of the Nile provides potential breeding pools for *A. gambiae*, which, as I was informed by Dr. S. Madwar, are not normally inhabited by Anopheline larvae.

Some additional records of A. gambiae at, and south of, Wadi Halfa.

Records quoted by Lewis (1944, 1949) suggest that *A. gambiae* has occurred on the Nile at least as far north as Wadi Halfa for many years, and the following are some additional records. *A. gambiae* is the only, or the predominant, Anopheline in all collections made between Zeidab and Debeira, and all reports of Anophelines or malaria almost certainly indicate the presence of this species.

Zeidab: present in 1910 (King, 1911), 1922 and 1928 (specimens in the collection at Wad Medani). "Berber Province": this species is sometimes responsible for fever which is prevalent in winter (King, 1908); Berber "is subject to mists from the Nile, and consequently feverish" (Gleichen, 1897). Gureir: *A. gambiae* found in December 1938. "Dongola Province": this species bred in a few river pools in the winter of 1906 to 1907 (King, 1908). "Northern Provinces": King, in official correspondence in 1926, wrote of this species as the chief carrier of malaria. A fever which was probably malaria has been known near Dongola for more than a century (Lewis, 1948b). Wadi Halfa: 1929, Mr. J. C. Edwards has informed the writer that he saw Anopheline larvae in that year; December 1940, Anopheline larvae in river pools mentioned in official correspondence by the District Commissioner; 1941, *A. gambiae* recorded from north of the town in annual report of Sudan Medical Service for that year; 1919 to 1945, according to reports of the hospital, malaria occurred during much

of this period, and was once described as an endemic disease of some importance at Halfa Degheim and Argin.

Events in the Wadi Halfa area since 1945.

After extermination in this area in 1945 the use of larvicides was almost completely stopped, apart from local action against *Culex pipiens* L. and occasionally *Aedes caspius* (Pall.). The local Public Health staff sprayed north-bound trains and vehicles, carried out certain other control measures, and made frequent inspections. The Mosquito Control Officer of the Ministry of Health made check inspections and the writer and his assistant visited the area from time to time. Monthly reports were exchanged from 1945 onwards between the Egyptian and Sudanese Ministries of Health. In the ten years which have elapsed since 1945 malaria has been almost unknown in the Wadi Halfa area and there has been no serious spread of *A. gambiae* in or into Egypt. It has been found from time to time as far north as Ferka in various months, including January and February, and can evidently winter there. It also reappeared for a few months in the Wadi Halfa neighbourhood.

The Egyptian Ministry of Health reported the finding of six larvae at Abu Simbel on 10th and 12th September 1950, a few at Ballana on 7th October, and some as far north as Anieba later in the same year. None was seen near Wadi Halfa till 12th December when a few larvae were found at Abdin. Treatment of all pools with DDT in oil was started on 1st January 1951 and has been continued ever since in accordance with the Egyptian suggestion that oil should be used for 80 km. in each direction from Faras, that is, from Saras to Anieba. It seemed, however, that this might mask any invasion by *A. gambiae* of the Wadi Halfa area in trains or cars, and accordingly six "detection pools" were constructed at Wadi Halfa. These are cement tanks one metre square and 30 cm. deep which are not treated with larvicide and are examined regularly. Some larvae of *A. gambiae* were found in the Second Cataract and at Abdin just north of it in March 1951, two were found in the Cataract at Gemai (A.A.B.), and some, also in the Cataract, at Sharti in May, and lastly two in a detection pool near the Nile Hotel at Wadi Halfa on 30th June 1951. These two are the only specimens found in the town since 1943.

The reappearance of *A. gambiae* in 1950 may have been due to its having persisted unnoticed in the reservoir area, or to spread from the south, possibly by one female in a train, during what was a year of unusually heavy rain. At Abu Hamed the monthly rainfall totals in 1950 and averages (of 34 years to 1954) for July were 110 mm. (far the highest ever recorded) and 5 mm., respectively, and for August were 27 and 13, respectively. At Wadi Halfa the respective figures were 29 and 2 (average of 18 years to 1954), and 1 and 0.1. Houses were destroyed by rain at Abu Hamed and there was a sharp outbreak of malaria further south at Shendi. At Wadi Halfa the humidity was high and there was a very unusual amount of southerly wind (ESE to WSW inclusive), 192 hours in July and 215 hours in August. Indirect observations in other parts of the Sudan suggest that wind has a marked effect on the spread of *A. gambiae* and some other mosquitos, and Causey, Deane & Deane (1943) noted that strong trade winds coincided with the spread of *A. gambiae* in Brazil.

Soper & Wilson (1943) suggested that *A. gambiae* might be exterminated in the Khartoum area and Soper (1948) visualised extermination for a thousand miles or more upstream from Wadi Halfa. The species could doubtless be exterminated for several hundred miles, but great expenditure and effort would be needed for the initial work and to prevent reinfestation by mosquitos carried in trains or on the south wind. It might be better to use available resources for routine measures in this and other parts of the country. In 1954, the Egyptian and Sudanese Ministries of Health began a joint campaign to increase the control

of *A. gambiae* and malaria between Dongola and Wadi Halfa, which should reduce the risk of northward movements of this species.

In years to come, breeding conditions may be radically altered, and land may be flooded as far south as Kosha, by the construction of a new high dam at Aswan.

Records of Abnormal Behaviour.

A. gambiae biting far from houses in various parts of the Sudan.

Females have occasionally been found biting man far from villages in places where they could not have fed on human blood and had perhaps therefore become unusually ready to bite man. Twice they were found biting at dusk (Lewis, 1948a, p. 150) and once at 1400 hr. in November beneath a tree at Wad Arud, a locality in uninhabited country where baboons and several other animals are common.

Trapido (1953), unlike De Meillon (1947), has suggested that certain instances of abnormal behaviour by *A. gambiae* in Africa may be due to local genetical differences. In the Sudan the presence of *A. gambiae* in uninhabited country, outdoor biting (once by day), and the occasional finding of adults in soil cracks in the Gezira are believed to be the effect of local conditions and not due to any variation of the species.

NOTES ON PRACTICAL IMPORTANCE.

Some species, particularly *A. coustani* var. *ziemanni*, *A. wellcomei* and *A. pharoensis*, cause much annoyance by biting, in places where they are abundant.

Malaria.

A. nili, to judge from its habits, may transmit malaria to some extent in the south. Wenyon (1908) believed it was the main vector at Nasir because it was numerous there.

The status of *A. dthali* as a malaria carrier in the Sudan, as in other countries (De Meillon, 1947), is uncertain. It is sometimes found at Port Sudan where malaria is unknown (Crispin, 1907; Edwards, J. C., 1949; Sudan, 1932) apart from imported cases and seven primary cases in 1937. According to the Sudan Medical Service report for that year, the rest of the coastal area was believed to be non-malarious. *A. dthali* is common near Erkowit, where malaria is rare and *A. gambiae* is sometimes found. At Kamob Sanha an outbreak of malaria occurred in November 1953, and *A. dthali* (A.P.F.) was the only Anopheline found, but *A. gambiae* was seen in the following October and may have been present before.

A. funestus is believed to be an important vector as far north as Jelebein.

A. gambiae is probably an important vector almost all over the southern Sudan and the only significant vector north of 14° except possibly in the Red Sea Hills.

Until 1947, *A. rufipes* was thought to be of no importance as a vector of malaria (De Meillon, 1947). Gelfand (1947), however, found it infected with sporozoites in Northern Nigeria but saw few adults in houses. Lewis (1948a) considered that *A. rufipes* was probably a vector in parts of the Sudan, where it bites man and is common in houses by day, sometimes greatly outnumbering *A. gambiae*. Holstein (1950, 1951) found *A. rufipes* infected and common in dwellings on the upper Volta, and later this species was described as a vector of local importance in certain parts of Africa (De Meillon, 1951; World Health Organization, 1951).

In the Jebel Auliya reservoir, *A. rufipes* breeds largely in *Naias pectinata* which forms a dense mass at the surface of the water. This plant grows thickly

where there are no floating grasses to shade it, as for instance in a new reservoir. The floating grasses near Kosti are a potentially valuable source of fodder and preparations are in progress for mechanical cutting and baling. This would probably allow *Naias* to increase, so it has been recommended that cutting should begin on the outer edge of the swamps where wave-action may be expected to prevent *A. rufipes* from breeding in *Naias*.

A. pharoensis shows a marked tendency to rest in living or dead vegetation rather than in houses on the lower White Nile (Lewis, 1948a), and as there is little vegetation the species is not thought to be an important vector of malaria there. It is desirable, however, to know to what extent females rest in thatch, as they do in Egypt (Barber & Rice, 1937), and to watch the effects of any growth of shrubbery near houses.

In addition to the above-mentioned species, there are six which have been found infected with malaria parasites elsewhere in Africa (De Meillon, 1947) but which have not been dissected in the Sudan.

It has long been known (Bray, 1904) that in most of the Sudan, except certain riverain areas in the south, malaria is essentially a disease of the rainy season. In nearly every annual medical report on the Sudan or its provinces a prominent place is given to comments on high or low rainfall and a corresponding bad or good year for malaria, even in areas where reservoirs or irrigation may increase the numbers of mosquitos. The relative importance of rain is due to its effect on *A. gambiae* and the fact that during the rainy season the humidity is high and the temperature neither very high nor very low.

According to Cruickshank (1936), malaria was universal in the southern Sudan, with a splenic index of over 90 per cent. in children up to 12 and a high degree of immunity in adults. Most infections were malignant tertian malaria, and blackwater fever was sporadic among northerners and foreigners. Nalder (1936) reported that the child mortality in Equatoria Province was estimated to be about 50 per cent. and was probably due to malaria.

In the desert reach of the Nile, malaria occurs in the early part of the year when *A. gambiae* breeds in residual pools.

Wuchereria bancrofti.

This parasite is briefly considered because *A. gambiae* and *A. funestus* are important vectors in Africa (Muirhead-Thomson, 1954).

Balfour (1904a, b) commented on the rarity of filariasis despite the presence of man-biting species of *Taeniorhynchus* and *Culex* in the Sudan, and expected to find it in parts of the southern Sudan infested with *T. uniformis* (Theo.). Waterfield (1918) commented on the rarity of filariasis at Suakin, and Ensor (1909) reported that "*Filaria nocturna*" occurred at Maridi and was very common in some other southern areas, but his statement has not been confirmed.

It is now known that *W. bancrofti* is absent from many dry parts of the world where vectors are abundant (Buxton, 1933), and it does not appear to be very common in Africa except in lower Egypt and different coastal areas and islands (Brumpt, 1949). Henrard, Peel & Wanson (1946) did not find it in the part of the Belgian Congo adjoining the Sudan, but Hawking (1940) recorded it from parts of Uganda near the Sudan.

Cruickshank (1936) reported that *W. bancrofti* had not been identified, but Woodman (1936) thought it occurred near Li Rangu although it had not been identified in spite of systematic searching. Woodman & Bokhari (1941) and Woodman (1948), while studying *Loa loa*, found 12 infections with *W. bancrofti* in the Zande area in 1937 and 1938, and Findlay, Kirk & MacCallum (1941) reported *W. bancrofti* in a Nuba who died at Malakal in 1935. Horgan (1945) reported *W. bancrofti* from Kadugli in the Nuba Mountains, an area where elephantiasis had occasionally been seen. He pointed out that, although *W.*

bancrofti had been regarded as extremely rare in the Sudan, the Kadugli finding showed the need for surveys in other areas where clinical filariasis was known. Woodman (1949) referred to the Li Rangu and Nuba findings and pointed out that in the former area there is no evidence that the parasite causes elephantiasis.

A. gambiae is common in both the infected areas, and *A. funestus* in the south. Many of the Nuba mosquitos are southern species and this area, which has a rather higher rainfall than surrounding districts, is probably a relict one in which some insects have been isolated by increasing dryness of the climate.

Summary.

The distribution of 2♂ species and three varieties of *Anopheles* in the Sudan is shown on maps. Notes are given on each one with particular reference to distribution. Reasons are given for regarding *A. rupicolus* Lewis as a synonym or local form of *A. rhodesiensis* Theo. The former spread of *A. gambiae* Giles into the Palaearctic Region in Egypt is discussed, and notes are given on its distribution in the Wadi Halfa area.

The general distribution of the Sudan Anophelines is discussed.

Notes are given on malaria and on *Wuchereria bancrofti*.

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References.

- ABBOTT, P. H. (1948). The Culicidae (Diptera) of Darfur Province . . .—Proc. R. ent. Soc. Lond., (B) **17**, pp. 37–48.
- AMERICAN GEOGRAPHICAL SOCIETY. (1951). Atlas of distribution of diseases. Plate 3. Distribution of malaria vectors.—Geogr. Rev., **41**, no. 4, maps.
- BALFOUR, A. (1904a). General routine work.—1st Rep. Wellcome trop. Res. Lab., pp. 49–57.
- BALFOUR, A. (1904b). Notes on the tropical diseases common in the Anglo-Egyptian Sudan . . .—J. trop. Med., **7**, pp. 115–120.
- BARBER, M. A. & RICE, J. B. (1937). A survey of malaria in Egypt.—Amer. J. trop. Med., **17**, pp. 413–436.
- BAZ, I. I. (1950). *Dixa aestivalis* in Egypt.—J. R. Egypt. med. Ass., **33**, pp. 1021–1028.
- BOYD, M. F. Ed. (1949). Malariology.—2 vols. Philadelphia, Pa., Saunders.
- BRAY, W. (1904). The southern Sudan—its climate and diseases.—J. R. Army med. Cps, **3**, pp. 369–387.
- BRUMPT, E. (1949). Précis de parasitologie.—6th edn., 2 vols. Paris, Masson.

- BUSVINE, J. R. (1948). Recent mosquito eradication campaigns.—*Nature. Lond.*, **161**, pp. 189–191.
- BUXTON, P. A. (1933). The effect of climatic conditions upon populations of insects.—*Trans. R. Soc. trop. Med. Hyg.*, **26**, pp. 325–364.
- BUXTON, P. A. (1944). Rough notes: *Anopheles* mosquitoes and malaria in Arabia.—*Trans. R. Soc. trop. Med. Hyg.*, **38**, pp. 205–214.
- CAUSEY, O. R., DEANE, L. M. & DEANE, M. P. (1943). Ecology of *Anopheles gambiae* in Brazil.—*Amer. J. trop. Med.*, **23**, pp. 73–94.
- CRISPIN, E. S. (1907). Port Sudan: its climate and sanitation.—*J. trop. Med. Hyg.*, **10**, pp. 329–330.
- CRUICKSHANK, A. (1936). Tropical diseases of the southern Sudan: their distribution and significance.—*E. Afr. med. J.*, **13**, pp. 172–177.
- DE BURCA, B. & SHAH, I. A. (1943). The Anopheline mosquitoes of Eritrea and their relation to malaria transmission.—*J. Malar. Inst. India*, **5**, pp. 235–245.
- DE MEILLON, B. (1947). The Anophelini of the Ethiopian geographical region.—*Publ. S. Afr. Inst. med. Res.*, no. 49, 272 pp.
- DE MEILLON, B. (1949). Eradication of the vectors of insect-borne diseases of man.—*J. R. sanit. Inst.*, **69**, pp. 177–183.
- DE MEILLON, B. (1951). Species and varieties of malaria vectors in Africa and their bionomics.—*Bull. World Hlth Org.*, **4**, pp. 419–441.
- EDWARDS, F. W. (1941). Mosquitoes of the Ethiopian Region. III. Culicine adults and pupae.—499 pp. London, Brit. Mus. (Nat. Hist.).
- EDWARDS, J. C. (1949). *Aedes aegypti* and mosquito control measures in Port Sudan.—*J. R. sanit. Inst.*, **69**, pp. 718–720.
- EGYPT. ANTI-MALARIA COMMISSION. (1919). Preliminary report of the Anti-malaria Commission.—55 pp. Cairo, Govt. Press.
- EGYPT. MINISTRY OF PUBLIC HEALTH. (1950). Report on *Anopheles gambiae* in Egypt 1942–1945. [*In Arabic.*]—166 pp. Cairo, Govt. Press.
- ENSOR, H. (1909). Report on investigations carried out in the Bahr-el-Ghazal Province on behalf of the Sudan Sleeping Sickness Commission, 1907–1908.—*J. R. Army med. Cps*, **12**, pp. 376–401.
- EVANS, A. M. (1938). Mosquitoes of the Ethiopian Region. II. Anophelini, adults and early stages.—404 pp. London, Brit. Mus. (Nat. Hist.).
- FARID, M. (1940). Malaria infection in *Anopheles sergenti* in Egypt.—*Riv. Malariol.*, **19**, pp. 159–161.
- FINDLAY, G. M. (1946). The internal combustion engine and the spread of disease.—*Brit. med. J.*, no. 4486, pp. 979–982.
- FINDLAY, G. M., KIRK, R. & MACCALLUM, F. O. (1941). Yellow fever and the Anglo-Egyptian Sudan: distribution of immune bodies to yellow fever.—*Ann. trop. Med. Parasit.*, **35**, pp. 121–139.
- GARRETT-JONES, C. (1950). A dispersion of mosquitoes by wind.—*Nature, Lond.*, **165**, p. 285.
- GELFAND, H. M. (1947). Natural malaria infection in *Anopheles rufipes* (Gough).—*J. trop. Med. Hyg.*, **50**, pp. 159–160.
- GLEICHEN, A. E. W. (1897). Report on the Nile and country between Dongola, Suakin, Kassala and Omdurman.—London, War Office.

- GREENE, H. (1954). Movements of subsoil water near Debeira.—2nd Congr. int. Comm. Irrig. Drainage, no. 4, pp. 45–50. New Delhi.
- HAWKING, F. (1940). Distribution of filariasis in Tanganyika Territory, East Africa.—Ann. trop. Med. Parasit., **34**, pp. 107–119.
- HENRARD, C., PEEL, E. & WANSON, M. (1946). Quelques localisations de *Wuchereria bancrofti* Cobbold au Congo Belge . . .—Rec. Trav. Sci. méd. Congo belge, no. 5, pp. 212–232.
- HOLSTEIN, M. (1950). Un nouveau vecteur du paludisme en A.O.F. *Anopheles rufipes* (Gough 1910).—Bull. Soc. Path. exot., **43**, pp. 140–143.
- HOLSTEIN, M. H. (1951). Note sur l'épidémiologie du paludisme en Afrique-Occidentale Française.—Bull. World Hlth Org., **4**, pp. 463–473.
- HORGAN, E. S. [1945]. Report on the Stack Medical Research Laboratories for the year 1944.—Rep. Sudan med. Serv. 1944, pp. 35–43.
- KHALIL, M. (1936). The Research Institute and the Endemic Diseases Hospital, Egypt. Fourth annual report, 1934.
- KING, H. H. (1908). Report on economic entomology.—3rd Rep. Wellcome trop. Res. Lab., pp. 201–248.
- KING, H. H. (1911). Report of the Entomological Section . . .—4th Rep. Wellcome trop. Res. Lab., (B), pp. 95–150.
- KNIGHT, K. L. (1953). The mosquitoes of the Yemen (Diptera, Culicidae).—Proc. ent. Soc. Wash., **55**, pp. 212–234.
- LEESON, H. S. (1937). The mosquitos of the *funestus* series in East Africa.—Bull. ent. Res., **28**, pp. 587–603.
- LEGA, G., RAFFAELE, G. & CANALIS, A. (1937). Missione dell' Istituto di Malariologia nell' Africa Orientale Italiana. Relazione.—Riv. Malariol., **16**, pp. 325–387.
- LEWIS, D. J. (1944). Observations on *Anopheles gambiae* and other mosquitoes at Wadi Halfa.—Trans. R. Soc. trop. Med. Hyg., **38**, pp. 215–229.
- LEWIS, D. J. (1945). Observations on the distribution and taxonomy of Culicidae (Diptera) in the Sudan.—Trans. R. ent. Soc. Lond., **95**, pp. 1–24.
- LEWIS, D. J. (1948a). The mosquitos of the Jebel Auliya reservoir on the White Nile.—Bull. ent. Res., **39**, pp. 133–157.
- LEWIS, D. J. (1948b). Early references to malaria near Dongola.—Sudan Notes, **29**, pp. 218–220.
- LEWIS, D. J. (1949). The extermination of *Anopheles gambiae* in the Wadi Halfa area.—Trans. R. Soc. trop. Med. Hyg., **42**, pp. 393–402.
- LEWIS, D. J. (1955). The *Aedes* mosquitoes of the Sudan.—Ann. trop. Med. Parasit., **49**, pp. 164–173.
- MACAN, T. T. (1942). A key to the Anopheline mosquitoes of the Mediterranean Region and the lands adjoining the Red Sea and the Persian Gulf.—J. R. Army med. Cps, **79**, pp. 1–11.
- MACMICHAEL, H. A. (1927). Notes on Gabel Haraza.—Sudan Notes, **10**, pp. 61–67.
- MADWAR, S. (1936). A preliminary note on *Anopheles pharoensis* in relation to malaria in Egypt.—J. Egypt. med. Ass., **19**, pp. 616–617.
- MARA, L. (1950). Studio sull' epidemiologia malarica del comprensorio agricolo di Tessenei.—Riv. Malariol., **29**, pp. 1–49.

- MUIRHEAD-THOMSON, R. C. (1954). Factors determining the true reservoir of infection of *Plasmodium falciparum* and *Wuchereria bancrofti* in a West African village.—Trans. R. Soc. trop. Med. Hyg., **48**, pp. 208–225.
- NALDER, L. F. (1936). Equatoria Province handbook. Vol. I. Mongalla.—169 pp. Khartoum.
- SALEM, H. H. (1938). The mosquito fauna of Sinai Peninsula (Egypt) with a description of two new species.—Publ. Fac. Med. Egypt. Univ., no. 16, 31 pp.
- SHOUSHI, Sir A. T. (1948). Species-eradication. The eradication of *Anopheles gambiae* from Upper Egypt 1942–1945.—Bull. World Hlth Org., **1**, pp. 309–352.
- SOPER, F. L. (1948). Species sanitation as applied to the eradication of (a) an invading or (b) an indigenous species.—Proc. 4th int. Congr. trop. Med. 1948, **1**, pp. 850–857.
- SOPER, F. L. & WILSON, D. B. (1943). *Anopheles gambiae* in Brazil 1930 to 1940.—262 pp. New York, Rockefeller Foundation.
- SUDAN. (1932). Report on the finances, administration and condition of the Sudan in 1931.—London, H.M.S.O.
- THEOBALD, F. V. (1906). Report on economic entomology.—2nd Rep. Wellcome trop. Res. Lab., pp. 67–96.
- TRAPIDO, H. (1953). Biological considerations.—In Logan, J. A. & others, The Sardinian project, pp. 353–374. Baltimore, Md., Johns Hopkins Press.
- WATERFIELD, N. E. (1918). Two cases of filariasis.—Brit. med. J., no. 2976, p. 54.
- WENYON, C. M. (1908). Report of travelling pathologist and protozoologist.—3rd Rep. Wellcome trop. Res. Lab., pp. 121–163.
- WOODMAN, H. M. (1936). Filariasis.—Rep. Sudan med. Serv. 1935, pp. 67–68.
- WOODMAN, H. M. (1948). Filariasis in the southern Sudan.—E. Afr. med. J., **25**, pp. 95–104.
- WOODMAN, H. M. (1949). Filaria in the Anglo-Egyptian Sudan.—Trans. R. Soc. trop. Med. Hyg., **42**, pp. 543–558.
- WOODMAN, H. M. & BOKHARI, A. (1941). Studies on *Loa loa* and the first report of *Wuchereria bancrofti* in the Sudan.—Trans. R. Soc. trop. Med. Hyg., **35**, pp. 77–92.
- WORLD HEALTH ORGANIZATION. (1951). Expert Committee on Malaria. Report on the fourth session.—Tech. Rep. World Hlth Org., no. 39, 30 pp.
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AIRCRAFT APPLICATIONS OF INSECTICIDES IN EAST AFRICA.

X.—AN INVESTIGATION OF THE BEHAVIOUR OF COARSE
AEROSOL CLOUDS IN WOODLAND.

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(PLATE VIII.)

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Introduction.

During the course of experiments in the Northern Province of Tanganyika Territory to determine the relationship between meteorological conditions and the deposition in open country of an aerosol released from an aircraft, trials were made to determine the relation, if any, between the deposit obtained and the mortality of tsetse flies (*Glossina palpalis fuscipes* Newst.) at a given point. The result of the first trial was striking, for all the experimental flies were killed almost at once, and flies in a spare cage some 800 yds. downwind of the track of the aircraft died within half an hour. Treatment of the gauze of this cage with a solvent showed that it was heavily contaminated with insecticide. Such a width of effective swathe is many times greater than that found practicable in control experiments in tsetse-infested woodland (*e.g.*, Hocking & others, 1953a; Hocking, Yeo & Anstey, 1954; Hocking, Burnett & Sell, 1954). In addition, the flies were found to be far more sensitive to small doses of insecticide than were

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any available physical or chemical methods of assessment, and it was plain that the latter methods alone would give information only on those parts of the swathe that were grossly overdosed. It was clear that in an investigation designed to measure the influence of various factors on the kill obtained in practice, the use of captive insects was essential, despite the obvious drawbacks of the method.

There were other reasons for using a biological method of assay. Since in most aerosol applications against *Glossina* the proportion of insecticide that penetrates the woodland is small compared with that initially released from the aircraft, and since the nature of air motion, and hence droplet motion, within woodland is complex, no satisfactory physical or chemical method could be devised to measure the amount and distribution of insecticide within the trees, and a series of experiments was thus planned using caged flies.

The trials were planned to determine, first, the relative extent of the lethal effect of a single swathe of insecticide over open ground and within bush, under various meteorological conditions. In the event, kills within woodland were so poor compared with those in the open that the investigation rapidly became a search for factors that might explain the excellent results obtained in practice (e.g., Hocking & others, 1953a; Hocking, Burnett & Sell, 1954; Hocking & Yeo, *in press*). In turn, the effects were investigated of various meteorological conditions, natural openings in the canopy, and the summation of sublethal doses from a series of swathes spaced as in actual operations. An attempt was also made to determine the extent to which an aircraft-emitted aerosol would drift into very thin bush in meteorological conditions unsuitable for sedimentation, the method used for the treatment of thicker woodland.

It is found convenient to describe the aerosol cloud as either sedimenting or drifting, these terms being related primarily to the nature of the atmospheric turbulence. Thus, when conditions are non-turbulent, an aerosol cloud will be subject to little drifting from the point or line of release, because of the light winds; it will be relatively persistent, droplets falling out under gravity according to size. Although, naturally, drift may occur, the dominant feature is sedimentation. In a turbulent atmosphere, normally associated with moderate or strong winds, buoyancy forces occur which offset the effect of gravity (to a degree dependent, again, on droplet size) and an aerosol cloud thus drifts downwind, being dispersed to a greater or less extent according to the degree of eddy motion of the atmosphere: the dominant feature is drifting rather than sedimentation. Although at any given time both factors are operating, it is in practice easy to determine which predominates, both visually, and by measurement of the degree of atmospheric turbulence.

An elaborate experimental technique was eventually developed which absorbed the entire available staff of the Colonial Insecticide Research Unit, and as the investigation had to be completed before the departure of one of the authors, some questions could not be investigated as fully as would normally have been desirable. In consequence, certain results are put forward tentatively, rather than unequivocally. It is unlikely that the work will be extended or repeated.

Description of Experimental Sites.

The experiments were carried out near Arusha (lat. 03° 28' S., long. 41° 41' E., alt. 4,500 ft.), in three areas, (1) Arusha airfield, some five miles from the township, representing open country, (2) a site about two miles from the airfield, known as Burka woodland, representing continuous woodland, and (3) an area, about 10 miles west of Arusha and five miles from the airfield, termed *Balanites* bush, carrying a sparse stand of *B. aegyptiaca* and representing thin woodland.

In addition, some trials, involving open country, were made in a treeless area alongside the *Balanites* bush, and others, involving the effect of breaks in the canopy, utilised clearings and gaps in Burka woodland.

The main base was Arusha airfield, where fundamental meteorological observations for all trials were made. These meteorological observations and the mode of conducting the physico-chemical assessment trials have been described by Thompson (1953) and Yeo & Thompson (1954). In the experiments described here, physical and chemical assessments were made and, in addition, cages of test insects were suspended at different heights on a meteorological tower and also at intervals downwind from the track of the aircraft.

The site known as Burka woodland was that previously used for observations on atmospheric turbulence in woodland (Thompson, 1953). It was about one mile square and consisted of an unusually even stand of *Acacia xanthophloea*, with scattered specimens of *A. usambarensis*. There were a number of small natural clearings, but it was possible to make an experimental layout in a part of the woodland with no breaks in the canopy. The general canopy top was flat and very uniform at a height of about 65 ft. There was no understorey, but considerable ground cover of various shrubs from about 6–13 ft. high. The canopy (Pl. VIII, figs. 1 & 2) was quite unlike that of any type of temperate woodland. It consisted of small leaves and interlacing fine twigs and had little depth. Over large areas it was continuous, the tree-tops meeting together, but even there only a relatively light shade was cast under the vertical sun, and direct, if attenuated, sunlight reached the ground in most places. Very few of the trees (even the *A. usambarensis*) bore branches at low or middle heights and, except in and near breaks in the canopy, there were no young trees. In addition to the clearings (Pl. VIII, fig. 3), there were gaps a few yards across between trees (Pl. VIII, fig. 2). This woodland would not be described as typical "tsetse bush," but it was the only suitable area available within a hundred miles of Arusha. Moreover, although somewhat taller, it closely resembled a large part of the Galapo Block at Kikore, in the Central Province of Tanganyika, which had supported a considerable number of *Glossina morsitans* Westw., and had been successfully treated with insecticide the previous year (Hocking, Yeo & Anstey, 1954). At the start of the trials in June 1951, the cool dry season was beginning and trees were in almost full leaf. They lost leaves gradually, but not completely, until October, when new leaves were put out rapidly.

In approximately the centre of Burka woodland a duplicate of the airfield meteorological tower was constructed. Radiating equally from the tower, eight paths were cut through the undergrowth along compass bearings, and it was thus possible to choose a path for the insect assessment layout that did not deviate from the direction of the wind, whatever that might be, by more than $22\frac{1}{2}^{\circ}$ (fig. 1). Down each path, convenient trees were chosen at intervals, originally of 100 yds. but later reduced to 25 yds. on some paths. Screw eyes were inserted into these trees at a height of 50 ft. and cords threaded through them so that cages of test insects could be hoisted to the desired levels. Additional trees were selected later when it was decided to investigate the effect of natural clearings. After a number of experiments had been carried out, considerable trouble was caused by theft of the cords, which sometimes made it impossible to hoist the full number of cages as planned.

On a tall specimen of *A. usambarensis* about 10 yds. from the tower, a flag was fixed on a pole projecting above the canopy. This was the marker over which the aircraft flew, crosswind, at a height as close to the tops of the trees as was safe. The flag also acted as an indicator of the wind direction in the free atmosphere. For trials involving the clearing, another flag was fixed above the tree marked A in fig. 1. During trials, layouts were made along the path most nearly in the downwind direction from the flag. When for various purposes other markers were needed, Verrey lights or smoke puffs shot vertically through the canopy were found adequate.

Four experiments were made in the *Balanites* bush. This was composed of

specimens of *B. aegyptiaca*, generally 15–20 ft. in height, but some of only 8 ft., occurring at a mean density of 32 per acre, the mean distance between trees thus being 25 yds. (Pl. VIII, fig. 4). This tree has a rounded top of interlacing thorny branches. Although evergreen, the trees did not bear many leaves at the time of the experiments. The ground was covered with short grass. Nearby was an area without trees, and it was thus possible to expose flies in the open and

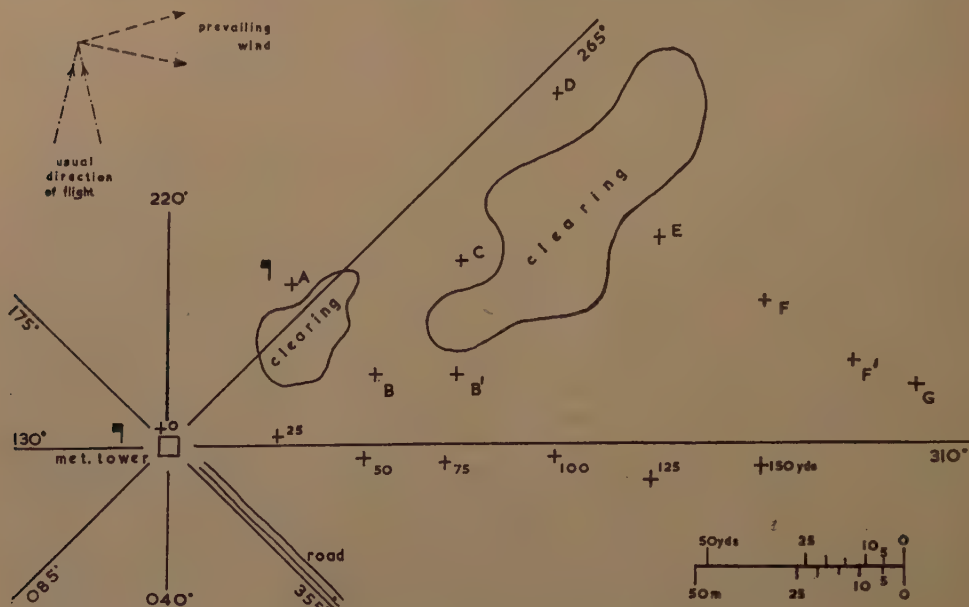


Fig. 1.—Plan of the experimental layout. The eight paths radiating from the meteorological observation tower are shown by solid lines. For trials involving single runs the 310° path was used almost exclusively, and along this the points of suspension of the test insects are shown by crosses, the adjacent figures indicate their nominal distance in yards from the tower. Also shown are the trees marked A–G used for investigations of the effect of clearings. The flags over which the aircraft flew are shown near tree A and the tower (in practice the aircraft passed a little to the right of the flags). All directions in degrees magnetic.

within the trees during the same spraying run. Cages of flies were either suspended at a height of 2.5 ft. from cross-arms on posts, or inserted in trees among the twigs, but away from large branches, at a height of 4–7 ft., according to the character of the tree (Pl. VIII, fig. 4).

Communication with the aircraft during trials was by radio, although when this was unserviceable, visual ground signals or smoke puffs and Verey lights were employed.

Test Insects.

The first trials (not reported here) were made using adults of *Glossina palpalis fuscipes* that emerged in the laboratory from puparia collected on the shores of Lake Victoria. All specimens were 4–10 days old. As the scale of experiments increased it became quite impossible to supply tsetse in the numbers required and attempts were therefore made to breed a substitute from locally-caught Muscid flies. Difficulties were encountered, but press of time made it essential to provide test insects before these difficulties were overcome, and resort was made to wild-caught specimens. These were always obtained in the same locality, a village

near the laboratory. Six Africans were on one occasion observed to sit in a ring for about an hour and a half, catching off each other. They returned with over 700 flies, and it was apparent that there was no need to go elsewhere for test insects. Except where otherwise stated, all the trials reported in this paper were thus carried out with locally-caught Muscid flies. The bulk of all catches was identified as *Musca (Eumusca) lusoria* Wied., but in view of the minute characters on which the determination of Muscids is based it is possible that some errors were made in the sorting of up to 2,000 specimens daily. Sorting was done on dead insects after the experiments had been carried out, since this was considered a more reliable procedure than sorting the live flies. All sources of variation were reduced as far as possible by using as many flies as could be caught. Any variation due to occasional misidentification, together with the uncontrollable variation inherent in the use of wild insects, is included in the residual variance in the statistical analysis of the experimental results. Thus, if the experiments are considered solely from the point of view of sampling the cloud of insecticide, the test material was adequate. All wild-caught Muscids were found to be more susceptible than laboratory-reared *G. p. fuscipes* to the DDT aerosol used. The regression of the kill of *G. p. fuscipes* on that of *M. lusoria* is highly significant (see Appendix), and therefore conclusions on the distribution of insecticide based on mortality suffered by the latter are applicable to the former. The application of the results obtained with caged flies to the case of free, wild flies is another and more difficult problem.

Insecticide and Dispensing Apparatus.

Experiments were started with the standard DDT solution used in previous tsetse-control experiments and described by Yeo & Thompson (1954); it consisted of 10 per cent. technical DDT in a mixture of equal parts of Shell Power Kerosene and Shell Diesoline. Those authors also described the apparatus used for producing the aerosol. For their experiments, four runs of the aircraft were necessary to permit suitable meteorological, physical and chemical assessments to be made. Four runs using 10 per cent. solution, however, gave such high kills when flies were in use that they were exposed to one run only, although later the DDT content was reduced to 1.6 per cent. and the insects exposed to four runs. At the end of the preliminary trials, when layouts of flies in the open were discontinued, a return was made to 10 per cent. DDT, one run only being made over the bush.

The emission rate was planned to be 10 gallons per minute in all trials but was checked for each experiment. Especially in the early trials, great difficulty was experienced in obtaining this desired emission rate.

Meteorological Observations.

During experiments, wind and temperature readings were made continuously, both at the airfield and in Burka woodland, according to the routine described by Thompson (1953). It was not always certain that conditions at the airfield and over the *Balanites* bush were identical, since observations of smoke over the latter sometimes showed the influence of katabatic winds from Mt. Meru. There was, however, no method of making detailed observations above the canopy and thus only the airfield figures are available.

The degree of atmospheric turbulence in the free air has been expressed for each trial as the value of the function F in the form used by Yeo & Thompson (1954, pp. 81-82).

$$F = \frac{T_2 - T_1 + 7.5\Gamma}{u^2}$$

where T_2 and T_1 are mean air temperatures (°F.) at 10 m. and 2.5 m.,

respectively, above ground level, Γ is the value of the dry adiabatic lapse rate and u the mean wind speed in feet per second at 5 m. F is zero in the neutral conditions of dry adiabatic lapse rate, positive when the atmosphere is stable and negative when unstable.

For a description of the nature of atmospheric turbulence and its effect on aerosols, Thompson (1953) and Yeo & Thompson (1954) should be consulted.

Experimental Procedure.

A series of preliminary experiments was first made to determine the types of layout required, using single cages containing 15 flies at various stations. The main series of experiments was carried out with sets of three cages at each station, since this not only gave better results, owing to the increased number of experimental insects, but made possible a statistical estimate of error, including that introduced by the use of a wild-caught population. In early experiments, flies were exposed both in the open and in Burka woodland, the time interval between the two parts of the experiment being cut as short as possible. Results in the open, however, were so consistent, and differed so widely from those in the woodland, that after a single replicated combined woodland and open trial the use of insects in the open was abandoned, to permit the extension and more efficient handling of the layout in the woodland.

Sample papers and wire gauzes were exposed alongside the flies in the early trials, but the flies were so much the more sensitive that eventually the physico-chemical assessments were confined to that part of the deposit which was dense enough for their use. The results thus obtained have been included in part in another paper (Yeo & Thompson, 1954).

Flies were exposed in cages $6 \times 3 \times 3$ ins. in size, made of a wire frame covered by a removable sleeve of mosquito netting closed with rubber bands, as shown in Pl. VIII, fig. 4. All cages of flies (10–20 per cage, according to supply) were prepared in the laboratory and stored in a moist atmosphere, with a pad of sugar solution for nourishment, placed on top of each cage, until collected for an experiment. They were carried to the site packed in clean containers in a vehicle always kept free from possible contamination by insecticide. Distribution along the experimental layout was delayed until the last moment and then the cages were rapidly put out. In the open they were suspended at 2.5 ft. above the ground and in the woodland were hoisted into trees as previously described. Control cages were suspended well upwind of the aircraft track, and were exposed during the whole operation.

After the final spraying run the flies were left *in situ* until the spray cloud had dispersed. This was usually tested by walking in from upwind and trying to detect it by smell. When there was no detectable trace of the aerosol a further five minutes were allowed to pass and flies were then removed as quickly as possible from their cages, to reduce the chance of further contamination from the netting. A start was always made at the upwind end of the layout and with the top set of cages, where contamination was likely to be heaviest. Flies were removed into "Kilner" jars by suction. Sucking tubes fixed in corks were plugged into plywood plates which took the place of the usual glass jar-tops and made a robust and easily handled piece of apparatus. When all the flies had been sucked from a cage into a jar, the sucking tube (with cork) was removed and replaced by a plug of cotton wool. Thus there was no chance of accidental contamination. Cotton wool at the bottom of the jar prevented damage to insects sucked violently into it. Sucking tubes were wiped in petrol-ether before being used on new cages and jars. The whole procedure required a large staff to carry it out expeditiously. When all the cages were empty, the closed jars of flies were transported to the laboratory and the tops replaced by mosquito gauze on which was placed a pad of sugar solution. Mortality counts were made at intervals,

depending to some extent on the time at which the trial had been carried out. Deaths were nearly complete within 12 hours and final counts were taken 21–24 hours after exposure. Control deaths among the tsetse used were almost unknown. *Musca* frequently showed no control deaths when used in woodland, but in the open, especially near midday, these flies sometimes suffered considerably (Table I).

Method of Analysis of Results.

The result of each experiment is given in that section to which it is principally relevant. Twenty seven trials were completed but some of these were spoiled, especially in the preliminary stages when techniques were being elaborated. Since these preliminary trials were repeated using the full triplicated arrangement (*i.e.*, three cages per station) they are not reported here in full. Each trial was given a reference letter which is used in all tables and in the text.

Control mortality is given for each trial but all the experimental mortalities given have been corrected by the formula (Abbott, 1925)

$$\text{Corrected mortality} = \frac{x - y}{x} \times 100$$

where x and y represent the percentage survival in untreated control and treated experimental samples, respectively. This correction is not perfect, since it can make no allowance for 100 per cent. kills that would have been less than this without control mortality, but its application is preferable to the use of uncorrected mortalities when comparing the results of different trials. All figures quoted give the mean mortality at the station.

The statistical treatment has been as follows. For single trials, where the data permitted, a full analysis of variance has been carried out on the corrected mortalities for each cage, converted to angles. If necessary, stations have been omitted to give truly orthogonal data. All procedures followed are those in Brownlee (1949). For comparison between trials this procedure would not have been legitimate for a number of reasons, in particular because the application rate of insecticide differed from trial to trial. In these cases, a straight comparison of the mean mortalities obtained in each trial has been made, using the t test, and it is thought that such a comparatively crude test is more likely than a sensitive one to reveal differences of practical importance. In addition, it makes it possible to utilise the results of trials in which the data were not fully orthogonal (owing, for example, to loss of insects from torn cages), and of at least one important trial of which some of the original figures are missing, although the means are fortunately available. In addition, a measure was required of random differences in dose from place to place. This might appear in column and row variance in an analysis of variance or it might merely increase the error variance to the point where all systematic differences are concealed. For this measure we have utilised the "total variance", which has been calculated in all cases from the mean corrected mortalities for each station, for the same reasons that favour the use of the t test.

Changes were made deliberately in the concentration of insecticide and the number of runs over any one layout, while emission rates varied despite all precautions. The amount of insecticide expended in each case has therefore been made readily comparable by calculating an "application rate". This is the product of emission rate (gals. per min.), number of runs and percentage concentration of DDT, divided by ten. Thus all variations are compared to a single run of 10 per cent. DDT, which has an application rate numerically the same as the emission rate and may be taken as the standard rate of application when the emission rate is 10 gals. per minute, both in these experiments and in practice.

TABLE I.
Summary of all trials carried out in open country.

Trial ref.	Date 1951	$F \times 10^3$	Wind speed (f.p.s.) at 5m.	Application rate*	Corrected percentage mortality at given distances (in yds.) downwind of aircraft track								Control mortality %
					30	100	200	300	400	500	600	700	
A	29.vi	—38.8	6.4	9.5	100	100	100	100	69	77	—	—	20
B	30.vi	—10.1	15.1	9.5	100	—	100	100	76	73	22	0	31
M	31.vii	—3.4	19.4	6.9	—	100	100	100	76	94	94	—	0
C	6.vii	—1.8	19.8	6.1	100	—	100	100	100	100	93	87	0
E	10.vii	+0.4	16.0	5.8	100	—	100	100	92	100	77	46	13
N	3.viii	+2.3	13.1	7.5	100	100	93	100	95	—	—	—	18
P	12.viii	+3.1	15.1	4.0	—	100	100	85	83	73	85	—	18
F	11.vii	+4.1	13.1	5.1	100	—	100	100	100	84	100	84	13

* See definition (p. 501).

Results.

(i) *Kills in open country.*

Table I summarises all successful trials carried out in open country, arranged in order of decreasing turbulence (increasing value of F). Trials A, B, C, E, F and N were done at the airfield. Trials M and P were part of experiments carried out at the *Balanites* site some five miles away, and the meteorological data, taken at the airfield, are possibly not so accurate, although check values made on site indicate reasonable agreement. Trials A, B, C and E were done with one cage of 15-20 flies at each station; for F, M, N and P three cages of 11 flies each were used. All cages were suspended 2.5 ft. above ground.

Owing to variations in application rate, it is difficult to make statistical comparisons between these trials. Unfortunately, none of them was made in conditions of very slight turbulence and, in all except trial A, wind speeds were relatively high. It is noteworthy that kills at points beyond 300 yds. fall off more markedly in trials A and B than in all the other trials except P (where the emission rate was abnormally low), despite the fact that the application rate was so much higher in A and B. These two were the only trials undertaken during the very strong super-adiabatic lapse rates of the midday hours and it is obvious that in both cases the upward (or convective) dissemination of insecticide was considerable as compared with its horizontal displacement. Evidently a drift kill of 100 per cent. can be relied upon with these application rates, but only for some 300 yds. downwind under the high lapse conditions typical of the midday hours in the tropics. It may be objected that as control deaths in these two trials were over 20 per cent., the 100 per cent. kills should not be taken at their face value. Inspection, showed, however, that in these cases deaths occurred rapidly, reaching 75 per cent. within one hour of exposure, at which time control deaths were below 10 per cent.

It is probably fair to compare trials A and B with the remainder as a group. The former have high turbulence and high application rates, the latter moderate turbulence and low application rates. Obviously, a given rate applied under a relatively low degree of atmospheric turbulence results in better kills at points more than 300 yds. downwind than does a higher rate applied in conditions of high turbulence. It is interesting to note that, over the range of F values experienced in these trials, Yeo & Thompson (1954) found that only about 16-30 per cent. of the emitted DDT was deposited on the ground, during a period of 90 seconds following emission. Such measurements of deposited insecticide, however, take no account of drifting insecticide that may kill flies at 2.5 ft. above the ground but that under turbulent conditions is ultimately dispersed into the higher atmosphere. Hence it is essential to distinguish between drifting and sedimenting insecticide, the latter of course being the more important when spraying above woodland has been undertaken.

It is concluded that in the conditions of moderate to high atmospheric turbulence covered by these experiments, with an application rate of 10 gallons per minute, 100 per cent. mortality can be expected to at least 300 yds. or more downwind in open country. The indication is therefore that good results might be obtained with the drift technique in country of thin and open vegetation during most hours of the day in the tropics.

(ii) *Drift spraying in very open woodland.*

The high kills in open country described in the previous section suggested that it might be feasible to treat very thin woodland under conditions of high or relatively high atmospheric turbulence such as are unsuitable for the treatment of continuous woodland. Such a possibility would be of considerable practical importance when areas of mixed woodland were being treated, because the period of the day during which aircraft could be employed might be increased, a shift

TABLE II.
Trials in *Balanites* bush.

Trial ref.	Date 1951	F × 10 ³	Wind speed (f.p.s.) at 5m.	Application rate	Corrected percentage mortality and estimated degree of protection* at given distances (in yds.) downwind of aircraft track									
						100	200	300	400	400A	500	600	Mean mortality %	Control mortality %
M	31.vii	-3.4	19.4	6.9	Trees	90+++	76+++	47+++	53+		46++	13++	54	0
P	12.viii	+3.1	15.1	4.0	Open	100	100	100	76		94	94	94	
					Trees	81++	74++	82+	84++		33+	54++	68	18
					Open	100	100	85	83		73	85	88	
R	15.viii	-5.9	15.5	5.6	Front	100	100	90	45	67	64		77	12
Q	14.viii	+3.2	11.2	9.0	Middle	86††	82†	38†	42††	9†††	10†		44	
					Rear	16	49	30	19	11	34		26	
					Front	100	91	47	32	68	60		66	0
					Middle	49††	45†	39††	13††	3†††	44†		32	
					Rear	64	12	6	33	0	32		24	

* Degree of protection afforded to test insects in trials M and P
(see Pl. VIII, fig. 4):—

+ almost unprotected
++ at least two feet of thin thorns upwind
+++ at least two feet of thick thorns upwind

Degree of protection in trials Q and R:—

† very thin thorns
†† moderately thick thorns
††† extremely thick thorns and creeper forming a complete screen.

being made from the thicker bush, treated under the low turbulence conditions of dawn, to other areas of sparse trees later in the day.

Investigations of this problem were carried out in the patch of *Balanites* described earlier. They consisted of two pairs of trials, the members of each pair having identical layouts. In the first pair (M and P), comparison was made between kills obtained simultaneously within the trees and in the open plain; in the second pair (R and Q), comparisons were made between kills obtained in cages suspended in front (upwind), in the middle and behind selected trees, which were different from those used in the first pair of trials. It was hoped to carry out one trial of each pair in conditions of low turbulence and the other in highly turbulent conditions. In the event, winds were too strong for low turbulence, but one trial of each pair was carried out with weak inversions, the other in conditions of instability. The differences between trials in the degree of turbulence, however, are of only slight significance and according to Yeo & Thompson (1954) would provide only a range of from 24 to 30 per cent. deposition of emitted insecticide. Inter-trial comparison is also made difficult by considerable variations in emission rate. In all four experiments insects were exposed to one run of 10 per cent. DDT and therefore the application and emission rates are equivalent. Aircraft height was 27–31 ft. above ground level.

Results, including mean mortalities for each trial, are given in Table II.

The protection afforded to each cage was assessed on an arbitrary scale, given as a footnote to the Table. The values given for percentage mortality and for degree of protection represent the averages of the three cages at each station. The trees had few leaves, but the twigs were green and flexible, somewhat thinner than a lead pencil and adorned with $1\frac{1}{2}$ -inch thorns of much the same thickness (Pl. VIII, fig. 4). The twigs tended to interlace and provide a screen, composed of elements of rather even size, through which objects could always be seen, except in the case of one tree (400 A), used in trials R and Q, which was smothered in dense creeper.

All statistical tests have been carried out on the original data, before taking means for each station: variation in the degree of protection afforded to the cages at any one station increased the intra-station variation.

Trials M and P should be considered together. In both cases the kill in the trees is significantly lower than in the open ($P = 0.001$), but direct comparison between the trials is complicated by the difference in application rates. The kill in the open for trial P is slightly lower than that for trial M but the difference, which is not significant, could well result from the application rate being only 60 per cent. of that of trial M. However, although the probability that it is due to chance is rather high ($P = 0.2$) the kill within the trees is higher in trial P. As this difference runs counter to the difference in application rates, more weight might be given to it than is justified by the level of probability.

In trial Q, there is a highly significant fall in mean mortality between the front of the trees and the middle or the rear of them ($P = 0.001$), but no significant difference between the middle and rear. Trial R shows a significant fall in kill between front and middle ($P = 0.05$), and front and rear ($P = 0.001$) and middle and rear ($P = 0.01$). These results suggest that under conditions of greater turbulence and higher wind speed (trial R), the aerosol is driven through the protective thorns more efficiently than by lighter winds in more stable conditions (trial Q), but that a certain density or thickness of the tree completely protects the insects. More detailed comparisons between trials R and Q are vitiated by the differences in application rates. Over the layout as a whole, the mean kill in all three stations was greater in the conditions of higher turbulence of trial R than in those of lower turbulence of trial Q, although this difference was only significant ($P = 0.05$) in the middle of the trees. That the only significant difference is in the centre of the trees suggests that kill in protected places was

due principally to insecticide drifting with the wind. If mortality was due principally to drops sedimenting more or less vertically it would be expected that kills would be higher behind the trees than in the middle, since cages in the former situation had little or no vertical but considerable horizontal protection, whereas those in the centre were shielded to a considerable extent from above but relatively less in an upwind direction. Thus the stronger wind experienced in trial R carried a higher proportion of the insecticide through the twigs than did the lighter wind of trial Q, and, moreover, compensated for the lower application rate in the former trial.

A surprising result of these trials in *Balanites* bush was the lower kills obtained immediately in front of trees, as compared with those in the open, in experiments carried out under similar conditions. Thus, the mean kill in the open in trial P, from 100 yds. downwind inclusive, was 88 per cent., whereas in trial Q the kill at the front of the trees (at 100–500 yds., inclusive) was only 66 per cent., despite a much higher application rate, and this difference is significant ($P = 0.01$). Similarly, in trial M the mean kill in the open was 94 per cent., while in trial R the kill at the front of the trees was only 77 per cent., the difference again being significant ($P = 0.01$). Admittedly, the application rate in this case varied in the same direction, but comparison with the various trials given in Table I makes it reasonably plain that the effect is real.

The results of these four trials in *Balanites* bush are to some extent contradictory, but since most of the between-trial differences in kill are not significant (which is not surprising in view of the small range of values of F) there is nothing to be gained in discussing them in detail. What is of obvious importance is that a comparatively small degree of protection, whether from tree foliage, or from other trees upwind, greatly reduces the width of the fully lethal swathe, and that even fully exposed flies do not suffer to nearly the same extent as do those in treeless country. Three possible reasons for this reduction in kill suggest themselves:—

- (a) attenuation of the aerosol cloud by impingement of droplets on trees upwind,
- (b) deflection upwards of the wind-borne aerosol over the bush as a whole,
- (c) deflection of the aerosol around or over each tree in turn, the cages being located within the boundary layer surrounding each tree.

With all these three possibilities the degree of protection afforded would be reduced with increased atmospheric turbulence, and there is perhaps some indication of this in that the low dosage of trial R has produced as great a kill as the higher dosage of trial Q. Taken as a set, however, there is no indication that, over the very small range of F values experienced, there is any systematic variation in kill as F increases.

It is clear that, at least with winds of 10–20 f.p.s., even small amounts of vegetation afford a considerable degree of protection. The effective swathe width obtained in such conditions will thus not be as large as would be expected from the experience of kills in open country. Nevertheless, the kills obtained in these experiments in thin woodland compare favourably with those obtained under favourable conditions in the continuous woodland experiments, and the method merits further consideration.

(iii) *Preliminary experiments comparing kills in continuous woodland and in the open.*

Five preliminary experiments were made in which one cage of 15–20 insects was used at each station in Burka woodland and at the airfield. The data obtained in the open for the first of these (trial A) have already been given in Table I, and the data for the counterpart of this trial carried out in continuous woodland are given in Table III. Four runs were made over the woodland,

giving an application rate of 38, as compared with a rate of 9.5 in the open. The results represent the most striking case observed of divergence between kills in the open and within woodland, presumably because the atmospheric conditions were highly unstable.

TABLE III.

Preliminary trial in continuous woodland; Trial A (29th June 1951).

Height of cages in tree (ft.)	Corrected percentage mortality at given distances (in yds.) downwind of aircraft track				
	35	50	150	250	350
50	43	50	50	38	—
25	8	53	17	35	31
5	—	12	46	22	25

F = -38.8×10^{-3} . Control deaths, 0. Application rate, 38.

Other trials under more favourable meteorological conditions and with application rates commonly used in practice (*i.e.*, about 10) showed higher kills than these but over a much narrower swathe. In consequence the horizontal intervals between cages were reduced to 25 yds. in the layouts of subsequent trials. A replicated layout was used in these later trials, and therefore the preliminary experiments are not reported in detail.

(iv) *The influence of meteorological conditions on the penetration of insecticide into continuous woodland.*

Six experiments using three cages at each station were made in this part of the investigation. Data for the most successful of them (J, K and W) are given in the first part of Table IV, the second part including additional information from four other trials (F, O, S and T) which were primarily designed to investigate other factors and therefore contain somewhat less detailed information than the first three. In all cases the meteorological data originated at the airfield but are considered representative of conditions at Burka woodland.

The very wide variations in the effectiveness of these applications is immediately apparent from a cursory inspection of the Table. Such an examination reveals, however, that large kills are restricted to those occasions of high positive F value (trials W, K and T) and that effective swathe widths are very narrow. Further statistical analysis, based on individual cage mortalities, yields the following results:—

- (a) *Trial J.* This is the only experiment in the Table with a negative value for F. The kill was greater in the higher parts of the trees, but not significantly so; variation with distance downwind is significant at the 0.05 level of P. Further analysis by Tukey's method (Tukey, 1949) shows only an irregular variation of mortality with distance downwind, that at 25 yds. being higher and at 100 yds. lower than the rest, which cannot be distinguished.
- (b) *Trials W and K.* Both trials were carried out in conditions of low turbulence, especially K. Kills in neither case were high, over 150 yds. the means were 44 per cent. for K and 40 per cent. for W. In both trials kills were higher in the upper parts of the trees, but not significantly

TABLE IV.
Experiments on penetration of insecticide into continuous woodland.

Trial ref.	Date 1951	F × 10 ³ in open	Wind speed (f.p.s.) at 5m. in open	Appli- cation rate	Height of cages (ft.)	Corrected percentage mortality (mean of three cages), at given distances (in yds.) downwind of aircraft track						
						0	25	50	75	100	125	150
J	24.vii	— 1.5	14.0	9.0	50 25 5	22 — —	63 32 29	47 32 27	42 32 19	44 7 23	34 29 33	37 41 23
W	30.xi	+19.8	4.5	9.0	50 25 5	97 87 30	58 17 8	56 52 21	27 33 40	10 38 63	49 31 42	60 35 41
K	26.vii	+54.0	3.6	7.0	50 25 5	98 87 25	83 69 73	57 38 45	66 39 36	41 42 6	23 16 12	26 10 29
S	29.x	+ 1.5	8.1	9.5	50 25	2 12	71 27	84 37	15 33	63 31	5 4	14
F	11.vii	+ 4.1	13.1	5.1	50 25 5	10 4 —	7 3 3	71 50 7	— — —	19 4 12	— — —	0
O	5.viii	+ 5.2	10.8	8.0	50 25 5	6 12 —	— 7 5	71 10 —	67 24 8	16 37 23	— — —	0
T	30.x	+26.4	7.0	5.5	50 25	19 16	100 12	89 44	46 30	27 54	— 54	8

so, and mortality varied from tree to tree to an important extent ($P = 0.001$), but there was no consistent decrease with increasing distance downwind. Considering that W was carried out after the trees were in full leaf and in less stable conditions, the kill obtained compares favourably with K. The rather higher application rate may be partly responsible for this.

- (c) *Trial F.* This was the last of the trials involving the simultaneous treatment of open country and continuous woodland, and mortalities at various heights in the latter (Table IV, F) should be compared with their counterparts obtained at a height of 2.5 ft. in the open and recorded in the last line of Table I. Application rates were identical, but whereas in the woodland the maximum kill was only 71 per cent. and mortality was negligible 100 yds. downwind, in the open 100 per cent. mortality occurred to 400 yds.

Table V summarises statistically such inter-trial comparisons as can be made. For these only the mean kill at each station has been utilised and, where the comparison is made between trials with dissimilar layout, mortalities and total variances have been recalculated for corresponding stations only. The Table falls into two parts:—

- (a) Trials J, K and W done with a full layout of 18 or more stations, and
- (b) Trials S, F, O and T which were more heterogeneous in character for a variety of reasons (*e.g.*, layout and emission rate).

Inspection of Table V shows that in section (a) there is a regular increase in both mean kill and variance with increasing F value; section (b) shows the same trend but with some irregularities. The only differences which are significant are those of both mortality and variance between trials J and K and trials J and W (all at $P = 0.05$). The variance of trial K is almost significantly higher than that of trial W at $P = 0.05$. When items in section (a) are compared with those of section (b) after recalculating for corresponding stations, significant differences in variance are not found, probably due to the reduction in the number of degrees of freedom. However, the variances of trials K and W both become greater than that of trial F, emphasising further the trend of variance to increase as F increases, *i.e.*, both dosage and kill become increasingly unevenly distributed as the atmospheric turbulence becomes less. Presumably this is due not solely to a narrower effective swathe width, for the kill at the tail of the swathe in trial W was as good as that in trial J (Table IV), but largely because of the extremely variable wind direction and calms which occur above and within the trees under quiet atmospheric conditions; such conditions lead to uneven dissemination of the emitted aerosol cloud.

Thus the trials discussed in this section confirm the general conclusions, drawn from other considerations, that low atmospheric turbulence, permitting a high degree of sedimentation, results in smaller losses of insecticide but increasingly uneven dosage amongst the trees. A further point noticeable in this series of trials is the filtering effect of the vegetation. This has been shown to be considerable in the case of drifting particles and there is no reason why it should be less with falling ones, other factors being equal. Kills are biggest at the higher levels, where the initial concentration of insecticide is a maximum. The gentle turbulence within the woodland must inevitably support some insecticide at the higher levels in the initial stages, and transport and exchange between upper and lower levels of a cloud that has passed the canopy occurs in later stages. The filtering action in the type of woodland under consideration would be greatest at the canopy, and hence the concentration of insecticide would be much reduced nearer the ground. This is probably the main reason for the comparatively poor kills at the foot of the trees. In addition, the greater the volume of air in the trunk space, the lower the overall concentration and the

TABLE V.
Statistical summary of inter-trial comparisons on penetration of insecticide in woodland
(replicated layouts).

Trial	Section (a)			Section (b)				
	J	W	K	S	F	O	T	
$F \times 10^3$
Mean mortality
Variance
Degrees of freedom

less the effect of insecticide returned to the lower part of the canopy by the internal convection currents in the woodland. It follows that in any woodland the shorter the trees the greater the opportunity for high kills.

The absence of 100 per cent. mortality at any of the stations suggested the probable importance of gaps in the canopy or of summation of doses as the factors ultimately responsible for the high kills experienced in practice by Hocking & others (1953a) and Hocking, Yeo & Anstey (1954), and these effects were accordingly investigated.

(v) *The influence of large gaps in the canopy.*

In an endeavour to determine the influence of large gaps in the canopy, advantage was taken of a clearing that lay between the 265° and 310° paths in Burka woodland to make a comparison between the kills obtained within the woodland and those that occurred around and downwind of the clearing. Fig. 1 is a plan of the area concerned and Pl. VIII, fig. 3, is a photograph of the upwind section of the clearing. The usual eyelets and cords were fixed to the trees marked A to G. Trees A to E were all on the edge of the clearing, but their spreading branches extended the canopy edge several yards beyond the points from which the test insects were suspended. Trees F, F¹ and G were intended to measure the degree of penetration into the woodland beyond the clearing, from which they extended in what had been the usual downwind direction. Unfortunately, during the experiments concerned, the wind tended to be more easterly and kills on F¹ and G can hardly have been influenced by the presence of the clearing, while F, instead of being some 35 yds. downwind of the edge, was nearly 50 yds., if not more, depending on the wind direction during and after emission of the spray. The aircraft flew over tree A and, owing to the track flown, passed over the 25-yd. tree along 310° of the woodland layout. Therefore, for the trials in this section, this tree becomes the first (0 yd.) of the woodland layout and the layout extends for only 125 yds., as far as the last (so-called 150-yd.) tree of the usual scheme.

Four trials, L, O, S and T, were carried out in this section, but their organisation suffered much from theft of the strings used to hoist the flies. During trial L, flies were used at three heights, around the clearing only. For the other three trials comparative layouts were made within the woodland along path 310°; the scheme was so extensive that only two heights (25 and 50 ft.) were used. The results are given in Table VI.

If trial L is compared with any of those in Table IV it can be seen that there has been considerable penetration of the insecticide downwind of the clearing. Specific comparison can be made with trial J, in which meteorological conditions were somewhat similar although the application rate was much higher. Owing to the higher wind in the case of L, the swathe has been displaced further downwind than is the case with J; for example, in L, tree B is obviously unaffected and C is on the upwind fringe, whereas F is well within the swathe and suffered much higher kills than the 125-yd. tree in trial J. Therefore, if we compare kills from 25 yds. to 100 yds. in trial J with those on trees C, D, E and F, from 45 to 120 yds. downwind, in trial L, we are comparing mortalities over approximately 75 yds. in each case and, moreover, probably favouring the trial carried out in continuous woodland. Despite this, and the much lower application rate in the clearing trial, the mean kill in the latter is very significantly greater (59 per cent. compared to 33 per cent., $P = 0.001$).

Trials O, S and T permit direct comparison between the effects in unbroken woodland and in the neighbourhood of clearings. In trial O, comparison at the two upper exposure heights can be made between the woodland, from 50 to 100 yards downwind of the emission line, and round the clearing, from 45 to 120 yds. downwind (trees B¹, C, E and F). The mean kill around the clearing was 63 per

TABLE VI.
Effect of clearings in assisting penetration of woodland by aerosol cloud.

Trial ref.	Date 1951	F × 10 ³	Wind speed (f.p.s.) at 5m. in open	Appli- cation rate	Corrected percentage mortality at given distances (in yds.) downwind of aircraft track																	Control mortality %
					Height of cages (ft.)	Woodland layout (see fig. 1)						Around clearing (see fig. 1)										
						0	25	50	75	100	125	A 0	B 15	B ¹ 45	C 45	D 75	E 90	F 120	F ¹ 150	G 160		
L	28.vii	—5.8	20.3	5.2	50							8	4	—	17	34	100	79	—	17	5	
O	5.viii	+5.2	10.8	8.0	25							19	2	—	13	80	100	89	—	4		
					5						11	0	—	4	6	89	97	—	14			
					50	6	—	71	67	16	—	12	—	38	100	—	100	45	—	19	0	
S	29.x	+1.5	8.1	9.5	25	12	7	10	24	37	—	20	—	16	57	—	100	48	—	12	—	
					5	—	5	—	8	23	—	—	—	—	—	—	—	—	—	—	—	
					50	2	71	84	15	63	5	22	64	—	38	33	65	14	2	—	14	
T	30.x	+26.4	7.0	5.5+	25	12	27	37	33	31	4	11	19	—	5	4	42	0	12	—	—	
					50	19	100	89	46	27	—	7	59	—	22	37	60	71	49	33	8	
					25	16	12	44	30	54	54	0	10	—	13	19	52	44	1	23	—	

cent. and in the woodland 38 per cent., the difference being significant at $P = 0.001$.

In trial S, the kill around the clearing was slightly, but not significantly, less than that in the woodland. Conditions were unfortunate in that drizzle was falling at the time, causing considerable difficulties in accurate flying.

Trial T was carried out in conditions suitable for a high degree of sedimentation, in contrast to those of trials L and O. The kill around the clearing was significantly poorer ($P = 0.02$) than in the woodland and there was little penetration downwind of the clearing.

Under conditions of slight or moderate turbulence in the free air, such as are normally associated with the moderate wind speeds of trials L and O, it would be expected that the aerosol would readily be carried by swirling air currents into and about the clearing and would penetrate beneath the canopy for some distance. The high mortalities around and downwind of the clearing in trials L and O can thus be satisfactorily explained. Different circumstances obtained, however, in the case of trial T. Here, free-air conditions were non-turbulent ($F = +26.4$), and the airflow would accordingly have approached a laminar state above the woodland, and clearings would have contained "pools" of dense, still air. Although sedimentation under gravity might occur into such a pool, dissemination would be very much restricted and penetration into the woodland particularly reduced. In this connection it is important to observe that although Thompson (1953) found that when conditions in the free air were non-turbulent, gentle turbulence and dissemination of insecticide nevertheless occurred beneath woodland canopies, such turbulence resulted from differential heating between the canopy and the ground. It could not occur in clearings where the canopy is absent. Hence in the first case (L and O) insecticide is actively distributed, and in the second (T), actively removed from circulation. It seems logical to suppose, therefore, on both theoretical grounds and the practical evidence of these trials, that openings in the canopy assist in increasing kills of resting tsetse flies under conditions of slight or moderate turbulence, but that under conditions of high atmospheric stability they probably have no such effect and may even reduce kills in their vicinity.

(vi) *The effect of the summation of swathes.*

A feature of the distribution of mortality in the experiments reported in this paper is the presence of a narrow band of high kills succeeded downwind by a wider band of low kills. This suggested that in practice, when parallel runs are made successively at regular distances normal to the wind (Hocking & others, 1953b, fig. 3), the overlapping of areas of sublethal dosage belonging to several successive swathes might produce higher kills than had been obtained in trials using single runs. Further, the distribution of insecticide should tend to be more even, drift from one swathe filling in the gaps left by the others.

Three trials were undertaken to test this idea. Unfortunately, accurate interpretation of the results required a steady wind throughout the series of spraying runs, and only the first trial (U) was so blessed. In this trial, three runs were made, one on each of three smoke puffs fired vertically through the canopy 75 yds. apart, and the whole layout of fly-exposure stations extended over a distance of 300 yds. downwind from the first run. Some of the separate cage mortalities for the trial were lost and analysis has to be based on station mean mortalities, which are available. The results are given in Table VII.

The mortalities below and downwind of the third run were by far the highest obtained in the whole series of trials, and may be compared with those obtained on the same stations in trial K (Table IV), which gave the greatest kill among the single run experiments and which, unlike trial U, was made in conditions of high stability. The mean mortality over all stations was 76 per cent. (U)

TABLE VII.
Summation of sub-lethal doses. Mortalities following three applications spaced at intervals of 75 yds.; Trial U (1.xi.51).

Position of spray run ..	1			2			3		
	150	100	75	50	25	0	25	50	150
Distance from tower (yds.) ..				<—Upwind			Downwind—>		
Percentage mortality at given height	50 ft.	—	63	94	98	83	94	85	90
	25 ft.					97	94	91	97
	5 ft.						70	56	71

F = $+2.2 \times 10^{-3}$. Mean wind speed, 13.5 f.p.s. Application rate, 7.2 for each of three runs.
Control mortality, 11%.

compared with 45 per cent. (K), and the difference is significant at $P = 0.001$. The total variance is also less, but not significantly so, if the complete swathes are compared. It is seen, however, that in trial U there is a sharp decrease in kill beyond 125 yds. which is far in excess of the maximum swathe width employed in practice. If the comparison is confined to the first 125 yds. of the swathes the significance of the difference in mortality remains unchanged, but the variance of trial U becomes significantly less than that of trial K ($P = 0.01$). The single-run trial that came closest to U, so far as meteorological conditions are concerned, was J. In trial U, the mortality was much higher, and although the total variance was also somewhat greater, the difference was not significant.

An attempt was made to repeat this experiment in trial V, of which the layout and the spraying procedure are shown in fig. 2. The layout, along two paths

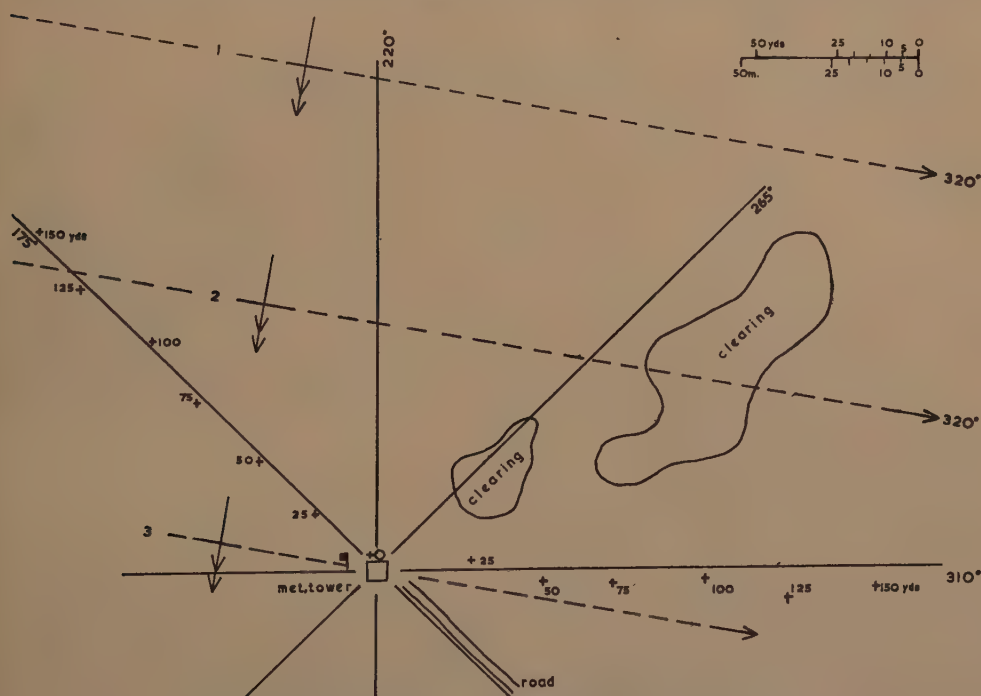


Fig. 2.—Trial V. The dotted lines with single arrow heads show the spraying runs of the aircraft, numbered in order, and the double-headed arrows show the wind direction during the trial. All directions in degrees magnetic. Points at which flies were suspended are shown by crosses.

(those at 175° and 310°) meeting at an angle of 135°, was deliberately designed to make it possible to carry on trials if small changes of wind direction took place, but between the hoisting of the fly cages and the arrival of the aircraft the wind changed by almost 90° and the experiment, so far as its original purpose was concerned, was spoiled. The results, however, are of sufficient interest to be included here. Three runs were made on smoke puffs fired vertically through the trees at 75-yd. intervals along path 220°. As the wind was from 230°, the runs were made on a track of 320° and were 72.5 yds. apart measured downwind. The third run passed over the flag at the junction of the paths and thus could not affect any of the test insects used. The atmospheric conditions encountered during this trial were noteworthy as being the most stable (highest positive F value) experienced during a whole year of research on the subject.

TABLE VIII.

Summation of sub-lethal doses. Mortalities from two applications spaced at an interval of 72.5 yds.; Trial V (see fig. 2) 29.xi.51).

Station along 175° path	150	125	100	75	50	25	Tower
Distance from second run (yds.)	10 Upwind	5 Downwind—>	20	34	45	60	70
Mortality at given height	50 ft. 25 ft.	100 90	100 100	100 100	100 64	100 45	68 39
Station along 310° path	25	50	75	100	125	150	
Distance from second run (yds.)	65 Downwind—>	68	65	60	60	52	
Mortality at given height	50 ft. 25 ft.	64 34	75 29	95 39	25 82	94 75	90 80

$F = +92.5 \times 10^{-3}$. Wind speed in open, 5.5 f.p.s. Application rate, 9.2 for each run.
Control mortality 9%.

Mortalities are given in Table VIII. Kills along the 310° path were, in general, conspicuously less than those on the 175° path ($P = 0.001$) but if the comparison between the two paths is confined to distances between 45 and 70 yds. downwind of the second run the difference is small and not significant. Thus, in accordance with the conclusions reached in the preceding section, the presence of the clearings less than 30 yds. upwind of the stations along the 310° path had no demonstrable effect, under the highly stable conditions obtaining, in increasing the kills at the stations along that path.

The kills along the 175° path from the tree at yd. 125 to the tower may be compared with trials U (Table VII) and K (Table IV). Compared with trial U, conditions in trial V were extremely stable and summation is from two swathes only instead of three. Mean mortality over corresponding stations is slightly less in trial V, but the total variance in V is much greater ($P = 0.001$).

Of the single-run trials, only K approaches V in atmospheric stability. In this trial, both mortality and total variance at corresponding stations were less than they were in V, but the differences are not significant. Thus, the second run made in the latter trial, 75 yds. upwind from the first, may have slightly increased mortality, but it has not reduced its irregular distribution. This is probably due to the extremely high F value, usually associated with very variable winds. The smallness of the increase in mortality may be due to the much heavier leaf cover in trial V.

Trial V, although it did not go according to plan, thus confirmed that with very stable conditions in the free air, clearings do not increase mortality within the woodland, and that under such conditions irregularity of coverage is increased, to such an extent as may offset the reinforcement of one swathe by drift from another swathe upwind, even when the wind in the free air is appreciable.

The final trial in this section (Y) was designed to duplicate an actual spraying operation, such as is usually carried out shortly after first light. Cages (three at each station) were hoisted to 25 ft. in trees along the 175° and 310° paths in Burka woodland and twelve spraying runs were made, commencing upwind at the edge of the woodland (fig. 3). The aircraft track was 220° and successive runs passed over smoke puffs fired vertically through the trees at 70-yd. intervals

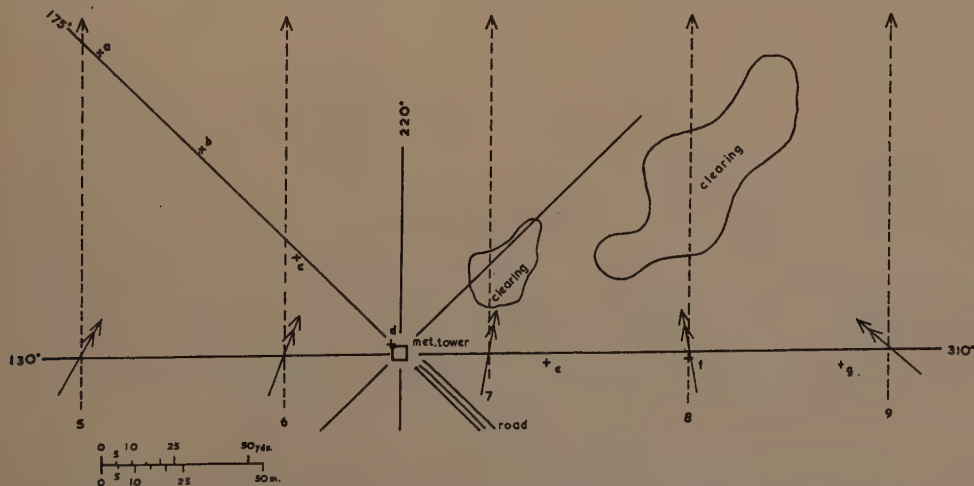


Fig. 3.—Trial Y, a duplication of normal spraying practice. Flies were suspended at the points a–g, marked with crosses. Successive runs were made as shown by the dotted lines with single arrow heads numbered 5–9, over smoke puffs fired from path 130° – 310° . The wind direction as the aircraft passed over this path on each occasion is shown by the double-headed arrows. All directions in degrees magnetic.

TABLE IX.
Duplicate of large-scale control operation; Trial Y (15.xii.51).

Swathe number	5	6	7	8	9						
Distance normal to aircraft track no. 5 (yds.)	0	5	40	70	75	110	140	160	210	270	280
Station reference (fig. 2)		a	b	c	d	e	f	g			
Mortality %		100	100	98	57	90	21	62			

Twelve runs over the major part of Burka woodland. Mean application rate, 12 for each run. F + 28.6 \times 10⁻³ decreasing to +5.4 \times 10⁻³. Wind speed in open 2.6-4.3 f.p.s. Direction changing from 050° to 345°. For directions during runs over the layout, see fig. 3.

along path 130° – 310° . Concurrent measurements of the value of F were made at the airfield, and the wind direction above the trees was observed for each spray run by checking the drift of the marker smoke-puff. The application rate for each run was 12. Mortalities are given in Table IX.

During the course of the trial the F value varied from $+28.6$ to $+5.4 \times 10^{-3}$. The wind speed was low throughout the trial, varying between 2.6 and 4.3 f.p.s., but the wind direction was extremely variable, changing from 050° at the beginning to 345° by the end. Thus whilst the aircraft was actually spraying over the layout the wind was almost directly along the aircraft track (fig. 3). Conditions above the trees were therefore such that dispersal of the insecticide cloud would be poor.

These conditions may frequently be met in actual operations. In the field, the direction of flight depends largely upon the topography and shape of the area concerned and can be fixed with reference to the prevailing wind only in a general way. Furthermore, the "prevailing wind" has little meaning when conditions are sufficiently stable to provide a high degree of sedimentation of aerosol, and on many days part of the operation, at least, may be carried out in conditions similar to those which obtained during this trial. In any case, kills such as that obtained beneath run 8 can hardly be blamed on a downwind spraying run since the aircraft passed immediately over the test insects (the tree concerned was a specimen of *A. usambarensis*, a species of denser growth than the *A. xanthophloea* which comprised 95 per cent. of the woodland). The purpose of the trial was to see whether, in actual operations, the various influences that gave rise to inequalities in coverage by single runs would be swamped by the repeated and regular swathes and the turbulence generated by the repeated passage of the aircraft. The answer is emphatically that this does not happen, under some conditions at least. The unusually high emission rate used in this experiment makes it clear that the result was not due to lack of insecticide, although the increasing leafiness of the trees at the time may have been a contributing factor.

Discussion.

It was mentioned in the introduction to this paper that the investigation became a search for factors that would explain the high mortalities achieved in large-scale tsetse-control experiments. In the present trials such high kills were never quite achieved, due probably to the use of caged insects and to the choice of an unusually regular type of woodland for the trials.

The highest kill produced in these woodland experiments was obtained in trial U, when three parallel swathes were laid from runs 75 yds. apart. In successful practice, runs have been made 55–70 yds. apart. The mean mortality obtained in trial U over all stations in the first 75 yds. downwind of the third run was 83 per cent. In view of the unusual height of the trees it may be better to take the mean mortality at the two upper heights only; this was 92 per cent. From the regression equation (B) given in the Appendix the expected corresponding mortality for *G. palpalis fuscipes* would be 44 per cent. (or 79 per cent., if the more favourable regression (A) for kills in the open is used). The initial kills in successful control experiments against *G. morsitans*, *G. swynnertoni* Aust. and *G. pallidipes* Aust. have been over 90 per cent. and it is therefore necessary to consider the relation between the experimental insects and free wild flies.

First, it seems unlikely that wild tsetse flies are more susceptible than those emerging in captivity, for these flies are notoriously difficult to maintain in good health as laboratory animals. There are no data available on the relative susceptibility of different species of *Glossina* to DDT aerosols, but for contact by foot Whiteside (1951) concluded that *G. palpalis fuscipes* and *G. swynnertoni* were of similar resistance but more, and not less, susceptible than *G. morsitans*.

and *G. pallidipes*, although even this difference may have been due only to the onset of hunger. Thus there is no indication that the discrepancy between kills in the present experiments and those in field control experiments is due to any greater susceptibility of the species treated in the latter. Thus, the inherent susceptibility of the test insects used in these trials favoured high mortalities. In addition, the exposed situations of the cages (from which the flies could not escape), especially those at the higher levels, plus any pick-up by the feet from the contaminated mesh of the cage, would tend to give high kills.

The use of cages may affect either the general level of mortality, its distribution in space, or both. The only effect which appears likely to be important in reducing kills is the direct shielding effect of the cage structure removing droplets from the air, and it is quite likely that this reduced our experimental mortalities. Reduction might also be caused by restriction on flight, since flying insects pick up more insecticide than do resting ones (David & Bracey, 1946). However, insects were seen to fly readily across the cages, and in any case tsetse are inactive creatures, especially so at dusk and dawn in the cases of *G. morsitans* and *G. swynnertoni*. Unless tsetse are stimulated to flight by sublethal doses, in time to enter the denser parts of the aerosol cloud before it disperses, restrictions on flight are not likely to reduce overall mortality. Our prime interest being to trace the spatial differences in the concentration of disseminated insecticide, restriction on the movement of the test insects was essential. If this led to a reduction in kill compared with practical control operations, it is a factor to be borne in mind when applying the results obtained, but it does not affect the primary purpose of the work.

The structure of the experimental woodland is likely to have reduced kills below those obtained in many tsetse habitats. The canopy, although thin, was composed of elements approximating to the dimensions of the flies, and therefore particularly liable to remove from the aerosol just those sized droplets which would be most efficient in impacting on the flies. Moreover, the proportion of small openings in the canopy was lower and the trees were taller than in normal woodland. This last feature would cause excessive dilution of the cloud of aerosol in the larger volume of air in the trunk space. Nevertheless, although these factors may indeed have been important, it must be borne in mind that tsetse in a very similar piece of woodland were treated very successfully in the previous year (Hocking, Yeo & Anstey, 1954).

Considering all these factors together, it appears legitimate to assume that although the general level of mortality may have been reduced below that frequently encountered in practice, its distribution has been measured with reasonable accuracy and the work has clearly indicated the manner in which a number of factors operate to influence the final result.

The first factor investigated was the turbulence of the atmosphere. Much previous work had shown that, in free air, low turbulence is essential for high recoveries of aerosol by sedimentation. Flies in natural conditions, and also when confined in cages suspended within woodland, are killed by impinging droplets which are both drifting under the influence of the turbulent air motions within the woodland and falling under the influence of gravity. Many droplets which kill in the top of the woodland probably never reach the ground at all, since they may be supported, or returned to the canopy after descent, by the air motions within the trunk space; if they do reach the ground, it may well be a considerable distance downwind. Hence, the distribution of mortality at tree-top level is not necessarily the same as its distribution on the ground. Nevertheless, it is found that the mean kill across a swathe is increased with increasing atmospheric stability. The effective swathe width (*i.e.*, the distance downwind over which effective kills are produced) is narrow, due to the low wind-speed associated with a non-turbulent atmosphere, most of the aerosol released from

the aircraft sedimenting into the trees before it can be carried far downwind. Apart from this, low turbulence results in more irregular distribution of the spray cloud within the woodland. This can be counteracted to a large extent by the practice of emitting the aerosol on parallel runs at regular distances apart, the tail of one swathe, which by itself would cause only a small mortality, reinforcing the effect of the next run downwind, not only by correcting some of the irregularities in this swathe (except in conditions of extreme stability), but also by adding to the doses. This reinforcing effect of successive swathes appears to be the most important factor in obtaining high kills, provided the direction of the wind is favourable.

Natural tsetse-infested woodland or bush is rarely as continuous in canopy as the Burka woodland used in these trials. The effect of natural openings was thus an obvious factor for test. It was found that in unstable conditions, especially with high winds, the kill around and downwind of a natural clearing is increased. In stable conditions the reverse obtains, the clearings largely contain a pool of stagnant air in which the slight turbulence necessary to act as a dispersing agent for the insecticide is absent; this slight turbulence has been shown to be generated in continuous woodland when non-turbulent conditions exist in the free air (Thompson, 1953). Carrying the argument a step further, to the treatment of very thin bush by drifting insecticide during turbulent conditions with reasonably steady wind direction, it was found that very sparse trees had a profound effect on the mortality sustained even in fully exposed cages, and a mere thin screening of twigs and thorns offered a considerable degree of protection. Although kills were much less than those obtained in completely open country, they were fully as good as those experienced under more favourable conditions in continuous woodland.

Finally, when a trial was carried out which duplicated a large-scale experiment in tsetse control, the results emphasised the extreme irregularity of kill which may occur in practice.

Summary.

In connection with studies on the control of tsetse flies (*Glossina* spp.) by insecticides, an investigation was made in Tanganyika Territory of the influence of a number of factors on the distribution of insecticide in woodland and open country. A solution of DDT in oil was disseminated as a coarse aerosol from an aircraft and its behaviour traced by the mortality suffered by caged flies. The test insects were wild-caught *Musca* (*Eumusca*) *lusoria* Wied., which proved more susceptible to the insecticide used than did *Glossina palpalis fuscipes* Newst.

In open country, complete kills were obtained with the standard application rate (defined as one run using 10 gals. per minute of a 10 per cent. solution of DDT) for at least three hundred yds. downwind of the line of emission, in all the atmospheric conditions encountered.

Tests of the possibility of treating very thin woodland in comparatively high winds (for aerial dispersals of aerosols) and slightly unstable conditions were spoilt by variations in the emission rate of the insecticide, but it was shown that quite small numbers of twigs upwind provided a considerable degree of protection to the test insects and that the kills in cages completely exposed on the upwind side of trees were considerably less than at corresponding distances downwind in completely open country. There was evidence that in high winds and slightly unstable conditions, penetration through the trees was better than with moderate winds and small inversions, but in both conditions there was mortality behind obstacles.

Preliminary comparisons between the kill in the open and in continuous woodland composed of *Acacia xanthophloea* showed that in the latter mortality

was greatly reduced and did not approach that frequently obtained in practical large-scale experiments in tsetse control. A search was made for factors which would increase the level of mortality.

Increased atmospheric stability caused greater average mortality at the expense of evenness of kill. This was not due solely to decreasing effective swathe width due to lighter winds.

Large natural openings in the canopy assisted the penetration of insecticide in unstable conditions, but in stable air the kill around and downwind of clearings was reduced compared with kills in unbroken woodland.

The principal factor in raising mortality to a generally high level was the summation of sublethal doses due to drifting downwind of the fringes of successive parallel swathes. The highest kill obtained in any of these trials was from summation of three swathes emitted 75 yds. apart, which produced a mean mortality of 84 per cent. for 75 yds. downwind of the third run.

An attempt to cover the whole area of woodland by emitting insecticide in a series of parallel runs, as in actual control procedure, showed that in conditions of low turbulence there yet may be great unevenness in the kill obtained. Mortality varied between 21 and 100 per cent., and this irregularity was almost certainly due to the fact that during each of the runs the wind was almost directly along the aircraft track. Such contingencies are unavoidable, for unsteadiness of wind direction is a constant feature of the stable, non-turbulent conditions in the free air that are needed to permit any substantial kill within continuous woodland.

The relation between these results and those obtained in practical control experiments is discussed. It is concluded that the use of caged insects and a particular type of woodland probably accounts for the comparatively low kills obtained in this investigation, from which, nevertheless, valid conclusions can be drawn concerning the variation in mortality from place to place.

Acknowledgements.

The scale of these trials made it necessary to ask the assistance of practically the whole staff of this unit, whatever their normal duties, and even of visitors on occasion. We tender our grateful thanks to them for their enthusiastic help, and also to the staff of Messrs. Airwork Ltd., who frequently assisted in work on the ground, as well as operating the aircraft. Our thanks are due, in particular, to Mr. K. S. Hocking, Officer-in-Charge, Colonial Insecticides Research Unit, for advice and encouragement in diverting the whole work of the unit. We are indebted to the management of Burka Estates Ltd. for allowing us to work on their property. The work was authorised by the Colonial Insecticides, Fungicides and Herbicides Committee and paid for from Colonial Development and Welfare funds.

We are grateful to Dr. F. van Emden, of the Commonwealth Institute of Entomology, for identifying the *Musca* used in these trials and to Mr. E. F. Whiteside for permission to quote his unpublished results.

References.

- ABBOTT, W. S. (1925). A method of computing the effectiveness of an insecticide.—*J. econ. Ent.*, **18**, pp. 265–267.
- BROWNLEE, K. A. (1949). *Industrial experimentation*.—4th edn., 194 pp. London, H.M.S.O.

- DAVID, W. A. L. & BRACEY, P. (1946). Factors influencing the interaction of insecticidal mists on flying insects. Part III.—Bull. ent. Res., **37**, pp. 177–190.
- HOCKING, K. S., BURNETT, G. F. & SELL, R. C. (1954). Aircraft applications of insecticides in East Africa. VIII.—Bull. ent. Res., **45**, pp. 613–622.
- HOCKING, K. S., PARR, H. C. M., YEO, D. & ANSTEY, D. (1953a). Aircraft applications of insecticides in East Africa. IV.—Bull. ent. Res., **44**, pp. 627–640.
- HOCKING, K. S., PARR, H. C. M., YEO, D. & ROBINS, P. A. (1953b). Aircraft applications of insecticides in East Africa. II.—Bull. ent. Res., **44**, pp. 601–609.
- HOCKING, K. S. & YEO, D. (*in press*). Aircraft applications of insecticides in East Africa.—XI.—Bull. ent. Res., **47**.
- HOCKING, K. S., YEO, D. & ANSTEY, D. G. (1954). Aircraft applications of insecticides in East Africa. VI.—Bull. ent. Res., **45**, pp. 585–603.
- THOMPSON, B. W. (1953). Aircraft applications of insecticides in East Africa. III.—Bull. ent. Res., **44**, pp. 611–626.
- TUKEY, S. W. (1949). Comparing individual means in analysis of variance.—Biometrics, **5**, p. 99.
- WHITESIDE, E. F. (1951). Experiments with DDT and tsetse flies.—Thesis, Univ. Wales.
- YEO, D. & THOMPSON, B. W. (1954). Aircraft applications of insecticides in East Africa. V.—Bull. ent. Res., **45**, pp. 79–92.

APPENDIX.

Relative Susceptibility of Test Insects and the Tsetse, *Glossina palpalis fuscipes*.

Five field trials were made in attempts to measure the relative susceptibility of the test insects, which were wild specimens of *Musca* (*Eumusca*) *lusoria* that had been caught as adults, and a species of tsetse (*Glossina palpalis fuscipes*), tested as adults 4–10 days old that had emerged in the laboratory from wild pupae. It was soon obvious that the *M. lusoria* used were more susceptible than the tsetse: in fact, difficulty was found in placing the insects in a range of insecticidal concentrations that would give mortality among the latter without exterminating the former. Two reasonably successful trials have been selected for analysis, one carried out in the open near the *Balanites* woodland, the other in Burka woodland.

Trial P. 12.viii.51. Balanites area. F = $+3.1 \times 10^{-3}$. Wind speed 15 f.p.s. Application rate, 4.

Mean corrected mortalities in corresponding stations:

	83	100	61	31	38	61	Control
<i>Glossina</i>							3
<i>Musca</i>	100	100	85	83	73	85	18

Correlation coefficient = 0.923 (significant at $P = 0.02$).

Regression equation (A): $y = 1.344x - 43.21$

where y and x are percentage mortalities of *Glossina* and *Musca*, respectively.

Trial T. 30.x.51. Burka woodland. $F = +26.4 \times 10^{-3}$. Wind speed 7.0 f.p.s.
Application rate, 5.5.

Mean corrected mortalities in corresponding stations:

<i>Glossina</i>	5	45	6	15	10	0	14	5
<i>Musca</i>	11	100	45	26	18	11	43	30
<i>Glossina</i>	36	5	18	11	25	5	10	21
<i>Musca</i>	53	53	58	9	21	36	18	59
<i>Glossina</i>	40	5	11	7				Control 0
<i>Musca</i>	70	43	48	32				8

Correlation coefficient = 0.684 (significant at $P = 0.001$)

Regression equation (B): $y = 0.4407x + 3.58$

where y and x are percentage mortalities of *Glossina* and *Musca*, respectively.

There is considerable difference in the slope of the two regression lines, which is probably due to the different conditions of each experiment leading to variations in the amount of insecticide picked up by the two species, but in both experiments *Musca* proved considerably more susceptible than *Glossina*, and there was a highly significant correlation between their mortalities.



FIG. 2. Burka woodland. A vertical photograph through the canopy of *A. xanthophloea* at its densest, showing a small gap where trees just fail to meet. Height about 65 ft.; picture covering 55 ft. lengthwise; greatest dimension of the gap 10 ft. Such small openings have little or no effect on the exchange of air masses above and below the canopy but admit droplets falling from the spray cloud.



FIG. 1. Burka woodland in its least broken form. A photograph taken diagonally upwards to show the strong vertical development of the trees, with twigs confined to their tops. All *Acacia xanthophloea*, except for one *A. usambarensis* on the extreme lower right.



FIG. 3. Burka woodland. A view along path 265° from near the meteorological tower, showing the small clearing (see text-fig. 1). Tree A is on the extreme left, C slightly to left of centre with the spreading top of D behind, B is to the right of centre and B' the more spreading specimen slightly behind and to its right. Behind B and B' is the principal clearing. Trees growing in and near clearings show much less vertical development, and deeper crowns than those within the woodland.



FIG. 4. *Balanites aegyptiaca* tree of fairly typical density; the degree of protection, according to the scale given in Table II, is "+ +", for the cages shown, but for cages placed in the centre of the crown would have been designated "+ + +" (trials M and P) or "x x" (trials Q and R).

THE MOSQUITOS OF LIBERIA (DIPTERA: CULICIDAE), A GENERAL SURVEY.

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In this, the third in a series of papers on the mosquito fauna of the African Republic of Liberia, the results of past studies and of a recent survey by the writer have been incorporated to present an up-to-date summary of all the available information on this little-known section of the Upper Guinean Forest.

Bequaert (1930) quotes Ziemann (1902) as the first to report the presence of *Anopheles gambiae* Giles in Monrovia. Bequaert himself lists 18 species of mosquitos collected in Liberia during the Harvard Expedition to Liberia and the Belgian Congo. Barber, Rice & Brown (1932) published the results of a malaria survey carried out on the Firestone Plantations. Briscoe (1948), collecting mainly near the coast, added several species to the list and later (1950, 1952) published his field notes and a survey of the ecology of the insects he had found, including mosquitos. Young & Johnson (1949) were the first to record the breeding of *Anopheles gambiae* var. *melas* Theo. on the coast. Gelfand (1954) gives a brief account of the Liberian Anophelines.

This paper includes the results of an extensive survey carried out by the writer and his staff while engaged in malaria control operations between April 1953 and May 1954 in the Liberian hinterland. All identifications have been checked as far as possible against specimens in the British Museum. The first two papers in this series described three new species of Culicini and hitherto unknown stages of ten other species.

Detailed malariological findings of the Kpain project will be reported at a later date.

Methods.

In order to carry on an entomological check of the malaria control operations, the operational area, over 800 square miles of sparsely populated country in the hinterland, was divided into sectors in each of which a number of fixed adult and larval catching stations were established. These and numerous random stations were visited by the author or members of his staff every two or four weeks. Routine collections of adults were made by hand and at random by space-spraying with a home-made pyrethrum preparation. Larvae were collected by making a counted number of dips with nets of standard size. All material was brought to the central laboratory for identification and recording.

Larvae were reared in the laboratory as often as practical, and special searches were made in tree holes and other small water containers. Adults were sought in outdoor resting places as well as indoors. There were almost no animal shelters in the area and indeed few large domestic animals.

Climate.

A hot, humid climate with seasonal rainfall prevails over the whole country. Briscoe (1952) has given a good account of the climate especially of the coastal

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areas. That of the hinterland is described in Schwab (1947), who quotes figures provided by Dr. George Harley of the Ganta Methodist Mission. Harley (1939) recorded an average rainfall of 83.37 in. over a 20-year period. Briscoe mentions 145 in. as the average annual rainfall at Robertsfield. Although the majority of the rain falls between March and November, there is usually a slight amount of precipitation even during the dry season. There are usually two periods of rain, the early rains from March or April to July, separated by the "short dries" of a week or two from the heavy rains, late July to October or November. A dry, desiccating wind, the Harmattan, blows for a few weeks during the dry season, causing a rapid transitory drop in the humidity.

In 1953, 93.36 in. of rain fell at Ganta. The average relative humidity at nearby Kpain was 95 per cent. at night and 55–95 per cent. at midday, depending upon the season. The lowest figures were only recorded during the Harmattan. Maximum day temperatures varied from 82–92°F., while the night temperature reached a minimum of 69–73°F. The lowest temperatures were recorded during the rainy season.

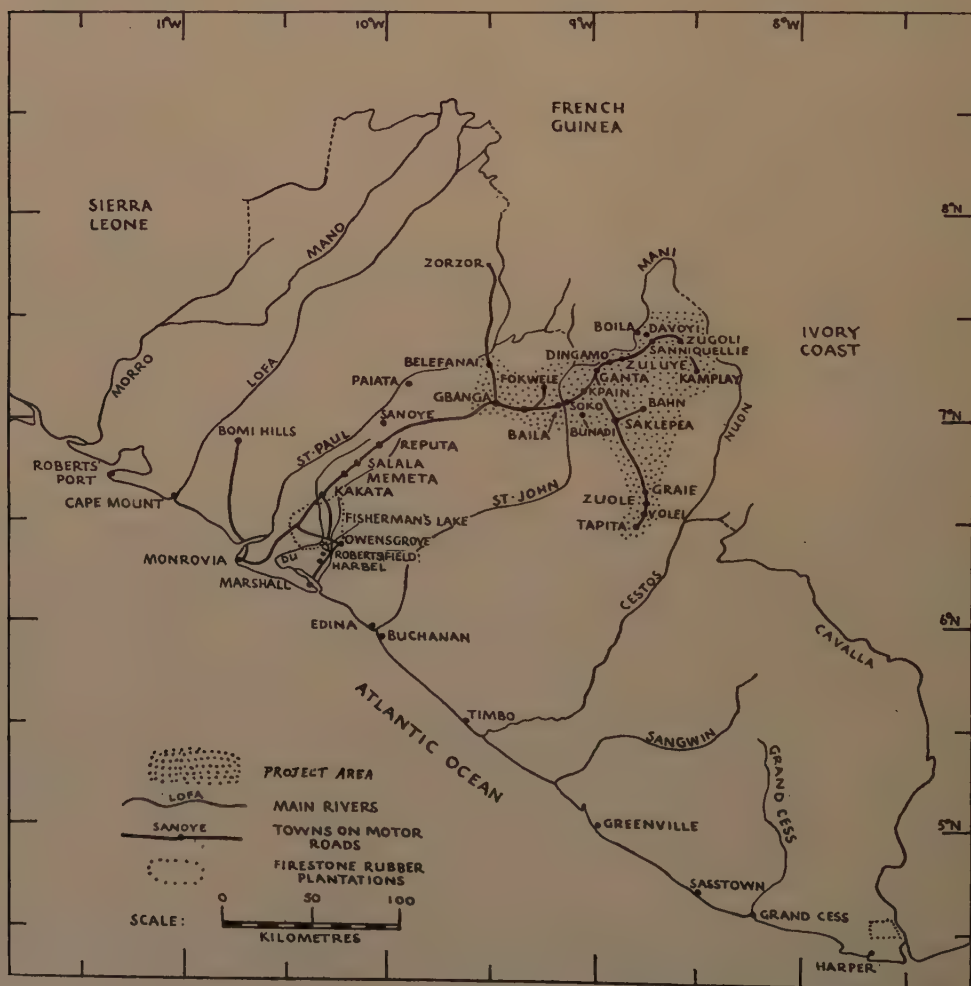


Fig. 1.—Sketch map of the Republic of Liberia, West Africa.

Topography.

Full accounts of the topography of Liberia have been given by Strong (1930) and Briscoe (1952). Kpain, the headquarters of the Malaria Control Project, lies on the main Monrovia-Sanniquellie road, 10 miles south-west of the border town of Ganta. Although most of the country lies within the Upper Guinean Forest region as defined by Chapin (1932), much of the land has been denuded of forest for rice cultivation. There remain, however, large tracts of fine primary forest away from the road. A few stands of the screw palm (*Pandanus*) are to be seen here and there and these yielded some of our most interesting species.

The project area lies mostly between 1,400 and 1,800 ft. above sea level. Its approximate extent is indicated by the stippled area in the accompanying sketch-map of Liberia. To the north-east of Kpain are the Nimba Mountains, whose peaks reach a maximum height of about 4,500 ft. Other than in the region of the Nimbas the terrain is flat with a few low hills here and there. The land is intersected by a profusion of small streams and swamps.

Localities.

The following is a list of the approximate latitudes, longitudes and altitudes of the main towns and villages mentioned in the following accounts.

a. Localities within the area of the Malaria Control Project.

	Latitude (° N.)	Longitude (° W.)	Approximate altitude (ft.)
Baila	7 04	9 09	1400
Bahn	7 02	8 47	1500
Belefanai	7 15	9 27	1300
Boila	7 35	8 38	1600
Bunadi	7 02	9 04	1400
Davoyi	7 34	8 44	1600
Dingamo	7 16	8 54	1400
Dubuyi	7 06	9 07	1400
Fokwele	7 07	9 12	1400
Ganta	7 15	9 00	1400
Gbedi	7 18	8 49	1500
Graie	6 43	8 45	1400
Jackson's Farm & Kitoma	7 19	8 47	1600
Kpain	7 09	9 05	1400
(misprinted on specimen labels as			
Sanniquellie	7 23	8 42	1600
Sokotown	7 04	9 09	1400
Tupapa	7 05	9 03	1400
St. Paul River crossing	7 22	9 30	1200
Vaa	7 06	9 04	1400
Venntown	7 10	9 03	1400
Volei	6 35	8 45	1400
Zorzor	7 47	9 31	1500
Zugoli (Zorgowin)	7 19	8 34	1600
Zuluye	7 16	8 51	1400
Zuole	6 41	8 45	1400

b. Localities mentioned in other publications.

	Latitude (° N.)	Longitude (° W.)	Approximate altitude (ft.)
Du River, Camp no. 3	6 15	10 25	0-1500
Firestone Plantations	6 18	10 25	0-500
Gbanga (also within project area)	7 05	9 25	1400
Harbel & Fisherman's Lake	6 18	10 25	below 500
Kakatown or Kakata	6 34	10 20	1000
Lengatown or Lengata	6 18	10 28	below 500

						Latitude (° 'N.)	Longitude (° 'W.)	Approximate altitude (ft.)
Memmeh	...	...	...	...	...	6 43	10 14	1000
Monrovia	...	...	...	...	...	6 18	10 45	below 500
Paiata	...	...	...	...	...	7 12	9 48	1000
Robertsonfield	...	...	...	...	...	6 20	10 19	below 500

LIST OF SPECIES.

The following list of the species of mosquitos occurring in Liberia includes records of earlier authors and those of the writer. Species taken in the writer's operational area are marked †; those first recorded here or in the first two papers in this series (Peters, 1955*a, b*) are marked *. Notes on the distribution and bionomics of these species are presented in subsequent sections, in which the months in which specimens were collected are shown thus:—i, ii, etc.

Tribe ANOPHELINI.

- † *Anopheles* (*Anopheles*) *coustani* var. *ziemanni* Grünberg 1902
- † " " *paludis* Theobald 1900
- † " " *obscurus* (Grünberg) 1905
- † " (*Myzomyia*) *cinctus* (Newstead & Carter) 1910
- † " " *-nili* (Theobald) 1904
- " " *smithii* Theobald 1905
- † " " *barberellus* Evans 1932
- † " " *-funestus* Giles 1900
- † " " *hargreavesi* Evans 1927
- † " " *-hancocki* Edwards 1929
- † " " *-gambiae* Giles 1902
- " " *-gambiae* var. *melas* Theobald 1903
- " " *pretoriensis* (Theobald) 1903

Tribe MEGARHININI.

- † *Toxorhynchites* *brevipalpis conradti* Grünberg 1907
- *† " *barbipes* Edwards 1913

Tribe CULICINI.

- *† *Harpagomyia* *taeniarostris* Theobald 1911
- *† *Hodgesia* *nigeriae* Edwards 1930
- *† " *cyptopus* Theobald 1910
- *† *Uranotaenia* *pallidocephala* Theobald 1908
- *† " *philonuxia* Philip 1931
- † " *balfouri* Theobald 1905
- *† " *chorleyi* Edwards 1936
- *† " *ornata* Theobald 1910
- *† " *yovani* van Someren 1951
- *† " *nigripes* Theobald 1905
- *† " *nigromaculata* Edwards 1941
- *† " *pseudohenrardi* Peters 1955
- *† *Ficalbia* (*Mimomyia*) *mimomyiaformis* (Newstead) 1907
- *† " " *mimomyiaformis* var. *pincerna* (Graham) 1910
- *† " (*Ficalbia*) *uniformis* var. *malfeyti* (Newstead) 1907
- *† *Taeniorhynchus* (*Coquillettidia*) *metallicus* (Theobald) 1901
- † " " *cristatus* (Theobald) 1904
- " (*Mansonioides*) *africanus* (Theobald) 1901
- " " *uniformis* (Theobald) 1901

- *† *Aedes* (*Finlaya*) *longipalpis* (Grünberg) 1905
 *† " " *ingrami* Edwards 1930
 † " (*Stegomyia*) *aegypti* (Linnaeus) 1762
 *† " " *simpsoni* (Theobald) 1905
 † " " *apicoargenteus* (Theobald) 1910
 † " " *africanus* (Theobald) 1901
 " " *luteocephalus* (Newstead) 1907
 † " " *vittatus* (Bigot) 1861
 *† " (*Aedimorphus*) *simulans* (Newstead & Carter) 1911
 " " *sp. nr. filicis* Ingram & De Meillon 1927
 † " " *tarsalis* (Newstead) 1907
 *† " " *yangambiensis* De Meillon & Lavoipierre 1944
 " " *minutus* (Theobald) 1901
 *† " " *cumminsi mediopunctatus* (Theobald) 1910
 " (*Banksinella*) *palpalis carteri* Edwards 1936
 " " *fuscinervis* (Edwards) 1914
 *† " " *sp. indet. (larva only) ? fuscinervis* (Edw.) 1914
 " (*Dunnius*) *argenteoventralis* (Theobald) 1910
 † *Eretmapodites* *chrysogaster* Graham 1909
 *† " *gilletti* van Someren 1949
 " *inornatus* Newstead 1907
 *† " *oedipodius* Graham 1909
 † *Culex* (*Lutzia*) *tigripes* Grandpré & Charmoy 1900
 † " (*Neoculex*) *rima* Theobald 1901
 *† " " *subrima* Edwards 1941
 *† " " *sunyaniensis* Edwards 1941
 *† " " *albiventris* Edwards 1922
 *† " " *horridus* Edwards 1922
 † " (*Culiciomyia*) *nebulosus* Theobald 1901
 † " " *cinereus* Theobald 1901
 *† " " *cinereus* var. *uniformis* (Theobald) 1910
 *† " " *cinerellus* Edwards 1922
 *† " " *macfieii* Edwards 1923
 *† " " *liberiensis* Peters 1955
 *† " " *harleyi* Peters 1955
 † " (*Mochthogenes*) *inconspicuus* (Theobald) 1908
 " (*Culex*) *bitaeniorhynchus* Giles 1901
 † " " *annulioris consimilis* Newstead 1907
 * " " *thalassius* Theobald 1902
 * " " *pipiens fatigans* Wiedemann 1828
 † " " *decens* Theobald 1901
 † " " *invidiosus* Theobald 1901
 *† " " *perfuscus* Edwards 1914
 *† " " *telesilla* De Meillon & Lavoipierre 1945
 *† " " *perfidiosus* Edwards 1914
 † " " *guiarti* Blanchard 1905
 *† " " *ingrami* Edwards 1916
 *† " " *schwetsi* Edwards 1929
 *† " " *grahami* Theobald 1910
 † " " *pruina* Theobald 1901
 20. † " " *moucheti* Evans 1923
 12

TRIBE ANOPHELINI—DISTRIBUTION, BIONOMICS AND RELATION TO MALARIA.

Anopheles (*Anopheles*) *coustani* var. *ziemanni* Grünberg.

LOCALITIES. Not recorded by Barber, Rice & Brown (1932) but common over most of the project area of the hinterland.

BREEDING PLACES. Natural collections of clear water such as swamps, small streams, ditches with slowly running water. Shade not important but water with green filamentous algae and some floating water plants preferred. May occur with *A. funestus* Giles.

BIONOMICS AND RELATION TO MALARIA. No adults of this species were found indoors or resting outside although the larvae were abundant. We are of the opinion that in this area var. *ziemanni* is a canopy dweller although we have no direct proof of this. Evans (1938) in East Africa found that this species entered a tent and Gibbins (1933) in Uganda showed that it was attracted by goats. No evidence of infection with malaria.

A definite seasonal variation in the numbers of the larvae of this group was noted, with a marked peak in November and December.

TAXONOMIC NOTE. The larvae of *A. coustani* var. *ziemanni*, *A. paludis* Theo. and *A. obscurus* (Grünb.) were not separated as a routine. All three were found together at times. By breeding out adults, the species were found to be present in the following proportions:—*A. coustani* var. *ziemanni* 12: *A. paludis* 19: *A. obscurus* 5.

The apical pale fringe spots on the wings of the adults from Kpain are small and the tibial and tarsal pale rings extended as in examples from Sierra Leone in the British Museum.

***Anopheles (A.) paludis* Theobald.**

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsfield (Briscoe, 1950); common all over the project area.

BREEDING PLACES. As the previous species with which it occurs.

BIONOMICS AND RELATION TO MALARIA. Two females were taken resting on the walls of houses indoors. No other adults were captured. This too may be a canopy dweller. De Meillon (1947) records that Wanson found an oöcyst rate of 5.5 per cent. and a sporozoite rate of 0.39 per cent. in 251 adults captured in the Belgian Congo. Briscoe (1950) records the capture of adults in stable traps but their absence from native dwellings. *A. paludis* is of no known importance as a malaria vector in Liberia.

***Anopheles (A.) obscurus* (Grünberg).**

LOCALITIES. Du group (Barber, Rice & Brown, 1932); common all over the project area together with the two previous species.

BREEDING PLACES. As the previous two species with which it occurs.

BIONOMICS AND RELATION TO MALARIA. No adults were captured indoors in the Kpain area but both sexes were captured in a fruit-baited trap suspended over a breeding site. Possibly also a canopy dweller. Of no significance as a malaria carrier.

TAXONOMIC NOTE. Barber, Rice & Brown (1932) captured larvae, from which adults were reared that were described as var. *nowlini* Evans 1932. The larvae differed in one character from typical *obscurus*, and the adults in two. Material

having these characters has not been seen from the hinterland, and De Meillon (1947) states that, since the differences from the typical form have been found to be variable, it seems advisable to sink the variety.

Anopheles (Myzomyia) cinctus (Newstead & Carter).

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Kpain, Sanniquellie, Bahn, Graie (iv, v, ix, x.1953).

BREEDING PLACES. Larvae were found in running water at the edges of small to medium-sized streams, clinging to vegetation, usually in full shade, and occasionally together with larvae of *A. nili* (Theo.).

✓ BIONOMICS AND RELATION TO MALARIA. Not known as a malaria vector. Adults were captured at rest in tree holes near Kpain.

Anopheles (M.) nili (Theobald).

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsfield, Harbel (Briscoe, 1950); Sanniquellie, Sokotown (iv, v.1953).

BREEDING PLACES. Mainly in small, shaded streams. Larvae were taken in May together with those of *A. cinctus*.

BIONOMICS AND RELATION TO MALARIA. Sometimes enters houses and may transmit malaria. Barber, Rice & Brown record an oöcyst rate of 14·6 per cent., sporozoite rate of 0·8 per cent. and filaria rate of 2·7 per cent. in 254 dissections of females captured in houses near the coast. We have found blood-engorged females resting in houses where they formed 1·5 per cent. of all Anophelines captured between April and June 1953.

TAXONOMIC NOTE. East African specimens of the adults have more extensive pale markings than those from West and South Africa. The Liberian examples are very dark and lack the basal pale interruptions of the costa and vein 1, but other examples in the British Museum from Njala, Sierra Leone have pale wings with broad white spots at the base. The genitalia and female pharynx of the Liberian specimens are identical with those of the type form.

Anopheles (M.) smithii Theobald.

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Cape Mount (Young & Johnson, 1949).

BREEDING PLACES. Rocky pools in connection with running water and containing dead vegetation, usually well-shaded. Young & Johnson found larvae in a small reservoir fed by a cool hill stream.

✓ BIONOMICS AND RELATION TO MALARIA. May enter habitations but of no known importance as a malaria vector.

Anopheles (M.) barberellus Evans.

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Kpain (x.1953).

BREEDING PLACES. Shaded streams, ditches with flowing water, possibly swamps.

✓ BIONOMICS AND RELATION TO MALARIA. Of no known importance as a malaria carrier. We have never seen this species indoors but it was captured frequently in October at rest in tree holes and among damp, well-shaded bush near Kpain. Males and females were taken in about equal numbers but larvae were not found.

TAXONOMIC NOTE. The wing markings are rather variable. In one male from Kpain the accessory costal spot of the left wing is fused to the sector spot, the joint spot being as long as the subcostal pale spot on vein 1; right wing normal. A second male lacks the accessory sector spot on the right wing; left wing normal. A female has fused sector and accessory pale spots on the costa and subcosta of the left wing while on the right wing the costa is normal but the sector and accessory sector spots of the subcosta are fused.

Anopheles (M.) funestus Giles.

LOCALITIES. Gbanga (ix) (Bequaert, 1930); Du group (Barber, Rice & Brown, 1932); Gbanga, Robertsfield, Harbel (Briscoe, 1950); common over the whole project area (see below under "Seasonal variations").

BREEDING PLACES. Permanent waters such as swamps; edges of streams and ditches containing flood water in the early and late rains. Always in clear water containing vegetation and well-shaded by this or by overhanging grass, shrubs, etc.

BIONOMICS AND RELATION TO MALARIA.

a. *Seasonal variations.*

Breeding in permanent waters, *A. funestus* is able to survive in quite large numbers in all seasons but is particularly common in the early rains and during the last few weeks of the heavy rains. Briscoe (1952) noted that *A. funestus* and *A. hancocki* Edw. together formed about 2 per cent. of the total Anopheline population in houses in a village two miles from Robertsfield. In the Kpain area, *A. funestus* was the dominant species in houses in February–May and November–December. During the heavy rains the proportion drops as the population of *A. gambiae* rises, the latter reaching a maximum in June and July.

b. *Endophily.*

This species is entirely endophilic in this area and also anthropophilic. It is consequently an easy species to control by house spraying with DDT and other residual insecticides, but detailed results of the control operations in this area are not yet ready for publication.

c. *Relation to malaria.*

A. funestus is second only to *A. gambiae* in its importance as a malaria vector in Liberia. It is relatively more important in the hinterland where it achieves a higher population density than on the coast. Barber, Rice & Brown (1932) recorded a sporozoite rate of 1.9 per cent. on the Firestone Plantations as well as a filaria rate of 2.5 per cent. in 2,698 specimens dissected. Rates as high as 27 per cent. have been found in Africa but these are exceptional. Sporozoite rates recorded in the Kpain area will be published at a later date.

Anopheles (M.) hargreavesi Evans.

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Graie (iv), Kpain (xi, xii.1953).

BREEDING PLACES. Larvae have been recorded from standing water containing *Pistia* and at the side of a stream among vegetation. The report of larvae in a borrow-pit by the Liberian collectors was probably in error. Later examinations of the alleged breeding site produced only larvae of *A. gambiae*.

BIONOMICS AND RELATION TO MALARIA. Not known to bite man in Liberia but in Nigeria may bite man outdoors and has shown a sporozoite rate of 5.4 per cent. Probably of no importance as a malaria vector in Liberia. Adults were captured in tree holes together with those of *A. barberellus*.

TAXONOMIC NOTE. Evans' type in the British Museum has the extra pale spot in the 3rd main dark area of vein 1 fused with the subcostal spot on the right wing; left wing normal. All the Kpain specimens have these two pale spots well separated. Variations occur in the size of the pale spots on the costa and 1st vein and the position of the extra pale spot on the third main dark area of the first vein. The wings are somewhat paler generally than the one illustrated by Evans.

Anopheles (M.) hancocki Edwards.

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsfield, Harbel, Fisherman's Lake (Briscoe, 1950); in most parts of the project area.

BREEDING PLACES. Margins of streams, ditches, shallow, grassy water-holes, always with clear water. In the present survey, larvae and pupae were found in a small pool with clear, slowly flowing water, partly shaded in August.

BIONOMICS AND RELATION TO MALARIA.

a. Seasonal variation.

Barber, Rice & Brown (1932) record *A. hancocki* as being common in houses in Liberia. Briscoe (1952) states that, together with *A. funestus*, *A. hancocki* made up 2 per cent. of the Anophelines captured in houses near Robertsfield. This species was found in all parts of the project area.

The peak population density occurred from September to December, following the heavy rains. In December in some localities it was the dominant species in dwellings.

b. Relation to malaria.

This is an endophilic species and has been taken biting man both in houses and outdoors. In view of the fact that a sporozoite rate of 2.7 per cent. has been found in this species in Uganda and of its endophilic and anthropophilic habits in Liberia, *A. hancocki* must be considered as a potential vector of some significance during the early dry season when it is at its maximum density whilst that of *A. gambiae* is low.

Anopheles (M.) gambiae Giles.

LOCALITIES. Widespread throughout the country.

BREEDING PLACES. Temporary pools, borrow-pits, swamps, ditches, rock pools, etc. Especially liable to breed in small ground pools near houses formed by digging out mud to plaster the houses, hoof prints, car ruts or any small pool with muddy water, fully exposed to the sun, which does not dry up too quickly.

BIONOMICS AND RELATION TO MALARIA.

a. Seasonal variations.

By virtue of its larval habitat, *A. gambiae* is essentially a rainy-season mosquito. Briscoe (1952) reported that *A. gambiae* was the most abundant mosquito on the coastal savannah. He did not differentiate between the typical form and var. *melas*. Bequaert found that *A. funestus*, not *A. gambiae* was the commonest species in Gbanga (in the hinterland) in September. This agrees with our findings in the project area for that season. Detailed figures will be published at a later date.

There was a marked rise in the population density of *A. gambiae* in the early rains but a drop following the heavy and continuous rain from late July onwards. In the early June rain, *A. gambiae* was by far the most abundant species. The maximum man-hour density reached was 24.8 by hand-catching in native huts in July.

Barber, Rice & Brown (1932) obtained roughly parallel densities by hand-catching on the Firestone Plantations. Their total Anopheline densities from February–May were 7.6, 6.2, 7.0 and 9.0 per room. They found the following percentages of the different species:—*A. gambiae* 45.5 (var. *melas* not differentiated), *A. funestus* 51.1, *A. nili* 2.8, *A. hancocki* 0.5. These figures cover total captures from February–April. By the end of May, *A. gambiae* formed 71.5 per cent. of all Anophelines captured.

Young & Johnson carried out a mosquito survey of various localities between May and October. They found the following percentages in a total of 1,153 adult Anophelines captured:—*A. gambiae* 94.28 (var. *melas* not differentiated), *A. funestus* 5.20, *A. hancocki* 0.26, *A. nili* 0.26. They reported that *A. funestus* was conspicuously commoner in their catching sites in the hinterland than in those on the coast. To summarise, it seems that *A. funestus* is commoner relative to *A. gambiae* (sensu stricto) in the hinterland inland from the coastal savannah belt, but until more figures are published establishing the proportions of the population of *A. gambiae* which are *gambiae* s.s. and var. *melas*, respectively, this can only be a surmise.

b. *Endophily and exophily.*

Holstein (1952) has suggested that there are two distinct races of *A. gambiae*, one endophilic and anthropophilic, the other exophilic and zoophilic. There is a certain amount of evidence arising from the work of the Kpain malaria control operations to support this view but lack of space prohibits further discussion here of this most important point.

Young & Johnson reported that, of 1,087 *A. gambiae* captured, only 22 were found in sites other than dwellings. Briscoe found that in June in the coastal area *A. gambiae* represented up to 98 per cent. of the mosquitos captured indoors. In the Kpain project area, *A. gambiae* represented 78.6 per cent. of all Anophelines captured indoors in about a 15-month period. During this time, in spite of prolonged searches, only a few male adults and no females were captured in outdoor resting places such as small chicken coops.

c. *Relation to malaria.*

A. gambiae is one of the most efficient vectors of human malaria. Sporozoite rates of up to 33.3 per cent. have been recorded in Africa. Barber, Rice & Brown (1932) recorded a rate of 3.5 per cent. on the Firestone Plantations but did not distinguish between *gambiae* s.s. and var. *melas*. Holstein (1952), working in French West Africa, has shown that the sporozoite rate in *A. gambiae* varies with the seasons, being highest towards the end of the rains, when the population density is highest and lowest during the dry season. Muirhead Thompson (1948) working at Lagos, Nigeria, demonstrated the reverse for *A. gambiae*, the sporozoite rate being in inverse ratio to the population density. In the case of var. *melas*, however, it appeared that the sporozoite rate varied more directly with population density.

Young & Johnson (1949) recorded a sporozoite rate of 6.45 per cent. in 543 dissections but did not distinguish between *gambiae* and var. *melas*.*

d. *Maxillary index.*

The mean maxillary index of females of *A. gambiae* captured in dwellings in the Kpain area was 14.1.

* Since the submission of this paper for publication, Gelfand (1955) has published the results of his investigations into the *Anopheles gambiae-melas* complex in Liberia. In a rural coastal area of the country he found an overall sporozoite rate of 5.7 per cent. (369 dissections) in *A. gambiae* and 1.4 per cent. (427 dissections) in var. *melas*. The filariasis infection rate was 19.5 per cent. (262 dissections) in *gambiae* and 27.1 per cent. (306 dissections) in var. *melas*. This paper deals in considerable detail with the bionomics of this group and should be studied in the original.

e. *Relation to filariasis.*

Barber, Rice & Brown (1932) recorded the presence of "Filaria" during routine salivary-gland dissections in 0.9 per cent. of 2,878 *A. gambiae*. Briscoe (1950) stated that adults of *A. gambiae* on the coast were found to harbour developing larvae of *Wuchereria bancrofti* in the thoracic muscles and that infective filariform larvae were occasionally found in the proboscis. In the hinterland, filariasis was rare and no filarial infections were recorded in any of the Anophelines dissected.

Anopheles (M.) gambiae var. melas Theobald.

LOCALITIES. Monrovia (Young & Johnson, 1949), Harbel (Gelfand, 1954).

BREEDING PLACES. Brackish water in lagoons and tidal swamps particularly in association with *Avicennia* mangrove.

BIONOMICS AND RELATION TO MALARIA. The population of this variety varies in relation to the high spring tides which flood the breeding places. It is an efficient malaria vector and it is possible that in the vicinity of its coastal breeding sites it is of greater importance as a vector than *gambiae* (sensu stricto). Muirhead Thomson (1947) has shown, however, that, given equal opportunities to acquire infection, *gambiae* is three times as effective a vector as *melas*. In a village near Lagos, Nigeria, he obtained sporozoite rates of 11.1 and 4.5 per cent., respectively.

TAXONOMIC NOTE. The two forms, *gambiae* and *melas*, may be distinguished in three ways:—

- a. the shape of the frill and platform of the egg,
- b. the reaction of the egg to immersion in sea water,
- c. the form of the larval pecten.

The works of Ribbands (1944), Chwatt (1945*a, b*) and Muirhead Thomson (1947, 1951) should be consulted for further details. Gelfand (1954) gives notes on the taxonomy and bionomics of this variety as studied by him in Liberia.

The pale wing spots are variable. The accessory sector spot and extra pale spot in the third main dark area of vein 1 may be fused to the sector and subcostal spots, respectively. The extra pale spot is absent in one of the Liberian specimens obtained from Harbel.

Anopheles (M.) pretoriensis (Theobald).

LOCALITIES. ??

BREEDING PLACES. In most kinds of standing water with partial shade, appearing to tolerate water containing red flocculent precipitates. It may also occur in streams. It was not found in the project area.

BIONOMICS AND RELATION TO MALARIA. Not normally anthropophilic or endophilic. Probably of no importance as a malaria vector in Liberia.

TRIBES MEGARHININI AND CULICINI—DISTRIBUTION AND BIONOMICS.

The number of mosquitos other than Anophelini captured at rest in dwellings during daytime searches was very small, amounting to a maximum of 1.3 per cent. of all mosquitos captured in this way. Adults of the tribe Culicini were captured more commonly in outdoor latrines, chicken coops, tree holes, the crevices in the bark of trees and in dense bush and other outdoor resting places. The majority of the adults in our collections were obtained by rearing from larvae and pupae found in a large variety of breeding sites. Larval and pupal pelts with the associated adults were thus available for the study of most of our species.

Few Culicini were ever seen in dwellings. *Taeniorhynchus africanus* (Theo.) is a house pest which bites viciously in the day-time near its breeding sites. *Aedes aegypti* (L.) and *A. apicoargenteus* (Theo.) were seen occasionally in houses and *Culex nebulosus* Theo. and *C. cinereus* Theo. were habitual frequenters of septic tanks and pit latrines.

Of the 71 or 72 species and forms of Megarhinini and Culicini now reported from Liberia, 59 species or forms were found within the limits of the Malaria Control Project's operational area. If the first mention of some species in the two previous papers (Peters, 1955a, b) in this series be included, 41 additions to the Liberian list, three of them new species, have been made.

***Toxorhynchites brevipalpis conradti* Grünberg.**

LOCALITIES. Gbanga (ix) (Bequaert, 1930); Robertsfield, Harbel (Briscoe, 1950); Kpain (viii).

HABITS. The larvae are carnivorous as we discovered to our cost when they cleared the contents of several breeding bowls full of *A. gambiae* larvae in an outdoor insectarium. From this particular batch of predators were raised 1 male and 1 female. Other adults were captured when they were attracted to an electric light after dusk.

***Toxorhynchites barbipes* Edwards.**

LOCALITIES. Kpain (viii).

HABITS. The carnivorous larvae are indistinguishable from those of *T. conradti* and live normally in tree holes and other small containers as does the previous species. One female was reared from a number of larvae found in tree holes.

***Harpagomyia taeniarostris* Theobald.**

LOCALITIES. Kpain (v).

HABITS. Larvae were found in the leaf axils of *Pandanus* together with larvae of *Uranotaenia ornata* Theo., *U. yovani* van Som. and a *Culiciomyia* species.

***Hodgesia nigeriae* Edwards.**

LOCALITIES. Kpain (iii).

HABITS. A single larva was found in a small, disused shallow well with clean water in association with larvae of *Uranotaenia chorleyi* Edw., *Culex cinerellus* Edw. and one of the *Anopheles coustani* group.

***Hodgesia cyptopus* Theobald.**

LOCALITIES. Kpain (vi), Volei (x).

HABITS. Larvae of this species were found in a shallow well, well-shaded and containing a small amount of vegetation. Others were found in a breeding bowl in the insectarium which they probably reached in water from the nearby swamp pool from which the bowl was sometimes filled when rain-water was not available.

***Uranotaenia pallidocephala* Theobald.**

LOCALITIES. Fokwele (v).

HABITS. A single male was reared from larvae found in swamp water together with larvae of *U. philonuxia* Philip and *U. chorleyi*. Two females were captured in native dwellings.

***Uranotaenia philonuxia* Philip.**

LOCALITIES. Fokwele (v).

HABITS. A single female was reared from a batch of larvae found in swamp water together with those of *U. pallidocephala* and *U. chorleyi*.

***Uranotaenia balfouri* Theobald.**

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Kpain (vi), Bahn (ix).

HABITS. Larvae were found in shallow ground pools with little or no vegetation and either with or without shade. No adults were taken indoors or out.

TAXONOMIC NOTE. Two larvae from Kpain have a small saddle-shaped dark brown spot on the dorsal part of the proximal half of the siphon which is otherwise pale. This spot is not evident in any specimens in the British Museum.

***Uranotaenia chorleyi* Edwards.**

LOCALITIES. Kpain (iii, v).

HABITS. A number of these larvae were found together with larvae of *Ficalbia mimomyiaformis* var. *pincerna* (Graham) and a member of the *Anopheles coustani* group in a disused, shallow well containing clear water and a small quantity of floating debris and water plants of the *Elodea* type. Other larvae were found together with those of *U. pallidocephala* and *U. philonuxia*.

***Uranotaenia ornata* Theobald.**

LOCALITIES. Kpain (iii, iv, v).

HABITS. Large numbers of adults were reared from larvae found in abundance in the leaf axils of *Pandanus* and the Liberian pineapple together with larvae of various *Culicomyia* species and *U. yovani*.

The larvae browse along the surface of the container moving by telescopic, jerky movements of the abdominal segments assisted by the long brushlike propleural hairs of the venter. The short, blunt lateral setae of the abdominal segments assist in holding the larva in position but are not themselves movable. The larvae will crawl out of the water of the container, browse along under the water film that follows them, then turn round and descend at leisure to the depths of the container. They feed on the bodies of others of their species but do not attack each other when alive.

TAXONOMIC NOTE. The adults are of the typical form.

***Uranotaenia yovani* van Someren.**

LOCALITIES. Kpain (iii, iv, v).

HABITS. The larvae were found together with those of *U. ornata* in the leaf axils of *Pandanus*. Their numbers were always much smaller. The larva is readily distinguished from that *U. ornata* by its covering of large stellate setae but the adults are very similar. The prothoracic pleural hair is independently movable in this species and assists in locomotion. The oral orifice is flat and lies ventrally, a good adaptation to the larva's habit of browsing, like *U. ornata*, over the surface of the container.

TAXONOMIC NOTE. The Kpain larvae are almost identical with specimens in the British Museum from Uganda. The only differences are that head seta d is single and e and f are double and longer than in the East African examples.

***Uranotaenia nigripes* Theobald.**

LOCALITIES. Kpain (viii).

HABITS. A series was reared from larvae found in the breeding bowls in the insectarium. The water in these may have contained the larvae when it was drawn from the nearby swamp pool.

***Uranotaenia nigromaculata* Edwards.**

LOCALITIES. Fokwele (v), Buyi (x), Kpain (x, xi).

HABITS. Larvae were found in the following situations:—a swamp pool containing very turbid water and a little vegetation, well-shaded; a swamp pool with little shade and much vegetation. Adults were found at rest in tree holes and crevices in the bark in high forest.

***Uranotaenia pseudohenrardi* Peters (1955b).**

LOCALITIES. Kpain (xii).

HABITS. Two males and one female were taken at rest in tree holes.

***Ficalbia (Mimomyia) mimomyiaformis* (Newstead).**

LOCALITIES. Du group (Barber, Rice & Brown, 1932) ? Robertsfield (Briscoe, 1950).

HABITS. Not noted.

***Ficalbia (M.) mimomyiaformis* var. *pincerna* (Graham).**

LOCALITIES. Kpain (v, vii), Bahn (ix), Buyi (x).

HABITS. The larvae were found in swamp pools and at the edge of a small stream. No adults were captured but several were reared from the larvae and correspond to this variety.

TAXONOMIC NOTE. The number of branches in the larval head setae is variable. One larval pelt has 8, 2, 3 and 3 branches in A, B, C and d respectively. Another pelt is as follows:—*Head*: Setae A, B and C with 10, 3 and 4 branches, d with 3. B and C both longer than A and more than half the length of the head. *Abdomen*: Comb spines 9 on one side, 11 plus 1 distal spine on the other side; siphonal index 3.2 in crushed specimen; 3 pecten spines; branches of subventral tuft simple; upper and lower caudal setae with 4 and 2 branches respectively.

***Ficalbia (Ficalbia) uniformis* var. *malfeyti* (Newstead).**

LOCALITIES. Bunadi (v, vii).

HABITS. Larvae were found at the edge of a large swamp the surface of which was covered by *Pistia* and in company with larvae of *Taeniorhynchus africanus* (Theo.).

***Taeniorhynchus (Coquillettidia) metallicus* (Theobald).**

LOCALITIES. Robertsfield (Briscoe, 1950).

HABITS. Briscoe recorded that "a few adults were captured in a stable trap."

Taeniorhynchus (C.) cristatus (Theobald).

LOCALITIES. Bahn (ix).

HABITS. A single female engorged with blood was captured in a native hut during the day.

Taeniorhynchus (Mansonioides) africanus (Theobald).

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsfield, Harbel (Briscoe, 1950); Sanniquellie (v), Bunadi (iii, vi, vii), Bahn (ix).

HABITS. A vicious day-time biter. A number of blood-engorged females were captured at rest in native dwellings in Bunadi.

There is a large pond covered with *Pistia* adjoining the town. Larvae of *T. africanus* and of *Ficalbia uniformis* var. *malfeyti* were found there in abundance. Briscoe captured adults in stable traps and in native dwellings.**Taeniorhynchus (M.) uniformis** (Theobald).

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsfield (Briscoe, 1950).

HABITS. A vicious day-time biter. Barber, Rice & Brown captured adults in dwellings. Briscoe captured them in dwellings and in a stable trap.

Aedes (Finlaya) longipalpis (Grünberg).

LOCALITIES. Kpain, Ganta (x).

HABITS. Larvae were found in well-shaded tree holes in the high forest. The larvae have a marked habit of hanging perpendicularly in the middle of the water for long periods at a time.

TAXONOMIC NOTE. The larval chaetotaxy is very variable. Kpain specimens show all the variations mentioned in Hopkins' (1952) account. The "gills" of the Kpain larvae are sharply lanceolate, the dorsal pair about three times as long as the saddle, the ventral pair a little shorter.

Aedes (F.) ingrami Edwards.

LOCALITIES. Kpain (iv).

HABITS. A single female was found dead in the writer's bedroom.

Aedes (Stegomyia) aegypti (Linnaeus).

LOCALITIES. Du River (viii), Gbanga (ix) (Bequaert, 1930); Du group (Barber, Rice & Brown, 1932); Robertsfield, Harbel, Kakata, Monrovia (Briscoe, 1950); Sokotown (vi), Monrovia (vi), Kpain (vi, x).

HABITS. Larvae were found in tin cans half buried in the ground and in bowls deliberately placed in the leaf axils of oil palms. Barber, Rice & Brown found the adults in dwellings as we did occasionally in Kpain. On the whole, this species was conspicuous by its scarcity.

TAXONOMIC NOTE. Kpain larvae have only 10-12 pecten spines.

Aedes (S.) simpsoni (Theobald).

LOCALITIES. Kpain (iii, iv, v).

HABITS. Larvae were found in water collected on a fallen banana leaf near the high bush and in water in pineapple tops. Larvae from the latter site were smaller and paler and the adults paler than those from the first site.

***Aedes (S.) apicoargenteus* (Theobald).**

LOCALITIES. Du River, no. 3 camp (viii) (Bequaert, 1930); Kpain (vi, vii, viii).

HABITS. Larvae were found in tree holes and hatched from eggs laid by wandering females in foul water in the breeding bowls in the outdoor insectarium. They were commonly found in company with *Eretmapodites oedipodius* Graham in the bowls. Attempts to raise a colony failed when the females refused to feed on human or guineapig blood.

***Aedes (S.) africanus* (Theobald).**

LOCALITIES. Kakatown (viii) (Bequaert, 1930); Robertsfield, Kakata (Briscoe, 1950); Kpain (x).

HABITS. Bequaert found this species biting man along a forest trail. Briscoe (1950) recorded that two adults were taken in a stable trap and a few in native huts. In Kpain, two females were captured at rest in tree holes. It is possible that some of the earlier records refer to the recently described *Aedes pseudo-africanus* Chwatt (1949) (see also Mattingly & Chwatt (1954)).

***Aedes (S.) luteocephalus* (Newstead).**

LOCALITIES. Robertsfield (Briscoe, 1950).

HABITS. Briscoe found the larvae during the rainy season in temporary pools. He found two adults in an abandoned wooden building near the breeding sites.

***Aedes (S.) vittatus* (Bigot).**

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsfield (Briscoe, 1950); Sokotown, St. John River (iv, vi), Kpain (x).

HABITS. This species was found commonly breeding in rock pools in the middle of the St. John River near Sokotown. The water in these pools is usually very green and turbid and fully exposed to the sun. Larvae of *Culex schweizeri* Edw. and *Anopheles gambiae* have been found in company with *Aedes vittatus* in these pools. Other larvae have been found in tree holes in Kpain. Briscoe captured a few adults in a stable trap and larvae in open ditches in a forest clearing.

***Aedes (Aedimorphus) simulans* (Newstead & Carter).**

LOCALITIES. Kpain (vi, x).

HABITS. The larvae of this species were common in tree holes in the bush round Kpain.

***Aedes (A.)* sp.nr. *filicis* Ingram & De Meillon.**

LOCALITIES. Robertsfield (Briscoe, 1950).

HABITS. Briscoe found larvae of a species near *filicis* in temporary rain pools in the rainy season. Similar larvae found in Kpain have been identified as those of a species of *Banksinella* and were described as such by Peters (1955b).

Aedes (A.) tarsalis (Newstead).

LOCALITIES. Paiata (x) (Bequaert, 1930); Kpain (v, x), Zugoli (vi).

HABITS. Larvae were taken in a mud hole near Kpain with those of *Culex ingrami* Edw. in October. Others were found in a small pool formed in the course of a ditch containing much grass and other vegetation. Adults were taken under the damp vegetation growing on the mud bank overhanging this pool. Bequaert stated that "both sexes (were) common near puddles of rain water along a native path in dense primary forest. The females did not attempt to bite".

Aedes (A.) yangambiensis De Meillon & Lavoipierre.

LOCALITIES. Kpain (v, x), Sanniquellie (vii).

HABITS. Larvae were found in Kpain in a small, water-filled pit.

TAXONOMIC NOTE. These larvae fit the somewhat incomplete description of De Meillon, Parent & Black (1945). The following details may be added from the examination of six larvae from Kpain. *Head*: Setae A, B and C with 10-13, 6 and 8 branches, those of B and C particularly thick and delicately plumose; d and f with about 6 very short delicate branches, e slightly longer with 2 branches. *Abdomen*: Upper caudal seta with 6-7 branches; lateral seta of saddle single, as long as the saddle; "gills" long and slender, pointed, dorsal pair 3 times as long as the saddle, the ventral pair only twice as long.

Aedes (A.) minutus (Theobald).

LOCALITIES. Du group (Barber, Rice & Brown, 1932).

HABITS. Barber, Rice & Brown captured the adults in houses.

Aedes (A.) cumminsi mediopunctatus (Theobald).

LOCALITIES. Sanniquellie (v).

HABITS. Larvae were found in temporary ground pools containing rotting maize stalks, grass and *Lemna* sp., together with larvae of *Anopheles gambiae*. The size of the larvae was most striking.

Aedes (Banksinella) palpalis carteri Edwards.

LOCALITIES. Gbangba (ix) (Bequaert, 1930); nr. Harbel (ix).

HABITS. Bequaert stated that the females were taken in dense primary forest. He did not specify the ssp. *carteri* but Edwards later (1941) listed his specimens in this category. We have one female taken from a window trap near Harbel.

Aedes (B.) fuscinervis (Edwards).

LOCALITIES. Du River, Camp no. 3 (viii), Paiata (x) (Bequaert, 1930); nr. Harbel (ix).

HABITS. Bequaert found larvae in an open ditch in a forest clearing near the Du River together with larvae of *Culex annulioris consimilis* Newst. and *Anopheles gambiae*. At Paiata he found adults near muddy puddles in swampy woodland. We have one female from a window trap near Harbel.

Aedes (B.) sp. indet. ? **fuscinervis** (Edwards).

A single batch of larvae was obtained from a ground pool together with larvae of *Culex cinerellus* in May near Kpain. They are similar to the larva of

A. palpalis and may be those of *A. fuscinervis*, the larva of which has not hitherto been described. They are described by Peters (1955b).

***Aëdes (Dunnii) argenteoventralis* (Theobald).**

LOCALITIES. Du River, Camp no. 3 (viii) (Bequaert, 1930).

HABITS. Bequaert observed a few males visiting flowers of a "cauliflorous tree" in the primary forest in day-time.

*** *Eretmapodites chrysogaster* Graham.**

LOCALITIES. Du River, Camp no. 3 (viii) (Bequaert, 1930); Robertsfield (Briscoe, 1950); Kpain (ii, vi, vii, viii, ix).

HABITS. Larvae of *E. chrysogaster* s.s., confirmed by the dissection of matched adult males, were found in an old calabash adjacent to a flooded path in a *Pandanus* grove together with larvae of *Culex cinerellus*. Larvae of this group of species were found in discarded tin cans containing rain-water and hidden under a large fallen leaf in the bush, also in tree holes. Briscoe found larvae in banana leaf axils and hollow bamboo stumps. He stated that the larvae were predacious. He did not find the adults indoors but in Kpain they were occasionally found flying indoors in the day-time. An attempt to raise a colony failed when the females refused to feed on man or guineapig.

***Eretmapodites gilletti* van Someren.**

LOCALITIES. Kpain (iv, v, vi, x).

HABITS. A series of males and females was reared from a single batch of larvae found in a tree hole in October. Others were found in other tree holes throughout the rainy season.

TAXONOMIC NOTE. The female and early stages of *E. gilletti* were described in part 2 of this series (Peters, 1955b).

***Eretmapodites inornatus* Newstead.**

LOCALITIES. Memmeh town (viii) (Bequaert, 1930); Du group (Barber, Rice & Brown, 1932).

HABITS. Bequaert found larvae in the empty shells of a large *Achatina* snail on a village refuse heap.

***Eretmapodites oedipodius* Graham.**

LOCALITIES. Kpain (vi, viii, x).

HABITS. Larvae were found in tree holes, in small bowls placed for their reception in the leaf axils of oil palms and in cultures of *Anopheles gambiae* in the insectarium. They were sometimes found in the last site together with larvae of *Aëdes aegypti* and *A. apicoargenteus*. Attempts to raise a colony of this species also failed because of the refusal of the adults to feed.

***Culex (Lutzia) tigripes* Grandpré & Charmoy.**

LOCALITIES. Lengatown (viii) (Bequaert, 1930); Du group (Barber, Rice & Brown, 1932); Robertsfield, Harbel (Briscoe, 1950); common throughout the Kpain project area.

* TAXONOMIC NOTE. Species of this genus recorded by Bequaert and Briscoe should be re-examined in the light of recent descriptions of new species very similar to those here mentioned.

HABITS. The larvae are predacious and may occur in any type of breeding site where there are other larvae. They were frequently found in the bowls in the insectarium where they did a great deal of damage to the cultures.

TAXONOMIC NOTE. The specimens recorded by Barber, Rice & Brown, and those from Kpain are of the var. *fusca* Theo. which is the typical West Coast form. It is likely that those taken by Bequaert and Briscoe would also be referable to this form.

***Culex (Neoculex) rima* Theobald.**

LOCALITIES. Monrovia (vii) (Bequaert, 1930); Du group (Barber, Rice & Brown, 1932); Kpain (x).

HABITS. Barber, Rice & Brown captured adults in houses. In Kpain 1 male was found in a tree hole.

***Culex (N.) subrima* Edwards.**

LOCALITIES. Kpain (iii, x).

HABITS. Adults, including males, were found resting on the sides of trees and in tree holes in the bush.

TAXONOMIC NOTE. Edwards (1941) described several new species of this group which can only be separated with certainty on the characters of the male genitalia. It is possible that some of Bequaert's and Barber's specimens were of these new species. In Kpain we found three members of this group, identified on the genitalia pattern, together in the same tree hole. We have also found several larvae of this group, not identifiable with certainty. They were in ground pools in Tapita and Kpain in May. Two females found on the sides of trees cannot be identified for certain but may belong to the next species.

***Culex (N.) sunyaniensis* Edwards.**

LOCALITIES. Kpain (x).

HABITS. Adults were found on the sides of trees and in tree holes in the bush.

***Culex (N.) albiventris* Edwards.**

LOCALITIES. Kpain (iii, x).

HABITS. Larvae and adults were found in well-shaded tree holes in the high forest. A number of larvae from one tree hole were observed to harbour a nematode parasite which could be seen coiled up occupying most of the body cavity. They were accompanied in some cases by numerous ova-like objects which occupied the remaining coelomic cavity even to the "gills" and siphon.

***Culex (N.) horridus* Edwards.**

LOCALITIES. Kpain (vi, x, xi, xii).

HABITS. Numerous adults of this species were captured resting in tree holes in the bush near Kpain but we did not find a single larva definitely assignable to it.

***Culex (Culiciomyia) nebulosus* Theobald.**

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsville, Harbel (Briscoe, 1950); Kpain (iii, vi, viii, x).

HABITS. Briscoe found larvae in tree stumps and hollowed logs and the adults among the nearby foliage. We have taken adults frequently in native huts and in outdoor latrines. The larvae were common in the Kpain area in foul water in latrines, septic tanks, stagnant water in old cooking pots and in discarded breeding bowls in the insectarium. The adults were common flying at dusk around the insectarium and would readily lay their eggs in any stagnant water placed at their disposal. The eggs would usually be associated with those of *C. tigripes* and sometimes with those of *E. chrysogaster*, *E. oedipodius* and *A. aegypti*.

Culex (C.) cinereus Theobald.

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Gbedi (vii), Kpain (iv, v, ix).

HABITS. Barber, Rice & Brown found adults in native dwellings. In Kpain they were occasionally found in houses and in outdoor latrines.

TAXONOMIC NOTE. Examination of a liaison pupal pelt revealed no clear difference between it and the pupa of *C. nebulosus*, a confirmation of Edwards' (1941) remarks.

Culex (C.) cinereus var. **uniformis** (Theobald).

LOCALITIES. Gbedi (vii), Kpain (iv, v, vi, viii).

HABITS. Taken together with the typical form in outdoor latrines. The male genitalia are exactly as in the type form but the females, when seen individually, are difficult to distinguish from those of *C. nebulosus*, which fly together with them.

Culex (C.) cinerellus Edwards.

LOCALITIES. Kpain (iii, vi).

HABITS. Larvae were found in a water-filled calabash together with those of *Eretmapodites chrysogaster*, in a disused well containing much floating debris and in two small ground pools with clear water and well-shaded.

TAXONOMIC NOTE. The females of the Kpain series are almost devoid of pleural scales.

Culex (C.) macfieii Edwards.

LOCALITIES. Kpain (iv, vi, viii, x, xi).

HABITS. This tiny species was the dominant tree-hole breeder in the Kpain bush. It was found sometimes together with larvae of *Eretmapodites gilletti* and *Aedes simulans* but usually by itself.

TAXONOMIC NOTE. The Kpain adults were identical with the type in the British Museum, but the larvae differed as follows:—siphonal index in crushed specimens 4.7–6.7, average 5.5. Hopkins mentions 8 as an average figure. The comb scales are less numerous (about 25) than in Hopkins' (1952) description (40).

Culex (C.) liberiensis Peters (1955a).

LOCALITIES. Kpain (iii, iv, v).

HABITS. Larvae were taken in the leaf axils of *Pandanus* together with those of the next species and *U. ornata*.

Culex (C.) harleyi Peters (1955a).

LOCALITIES. Kpain (iii).

HABITS. Larvae were found together with those of the previous species (*q.v.*) and of *U. ornata*. They fed by browsing over the surface of the container, moving quite rapidly.

Culex (Mochthogenes) inconspicuus (Theobald).

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Tapita, Tuopu (iv, v); Kpain (iv, x).

HABITS. Larvae were taken by Barber, Rice & Brown. In the Kpain area larvae were found in water at the edge of shaded streams and in a drain leading from a shallow well. Two males and one female were found at rest in tree holes near Kpain.

Culex (Culex) bitaeniorhynchus Giles.

LOCALITIES. Robertsfield, Harbel (Briscoe, 1950).

HABITS. Briscoe found larvae of this species in rice fields, ditches and hollow tree stumps in the rainy season. It is not clear from his account if the identification was made from larvae alone or from associated adults.

Culex (C.) annulioris consimilis Newstead.

LOCALITIES. Du River, Camp no. 3 (vii) (Bequaert, 1930); Du group (Barber, Rice & Brown, 1932); Robertsfield, Harbel (Briscoe, 1950); Kpain (iv, v, vi, viii, ix, x).

HABITS. Bequaert found the larvae in an open pond near a forest clearing together with those of *Anopheles gambiae*. Briscoe also found them in association with *A. gambiae* in temporary puddles in a forest clearing exposed to sunlight. In the Kpain area they were often found in clear, still or running water in association with green filamentous algae. They have been found together with *Anopheles* of the *coustani* group, *A. funestus* and *Culex grahami*.

Culex (C.) thalassius Theobald.

LOCALITIES. Harbel (ix).

HABITS. The larvae thrive in brackish water in similar sites to those in which *Anopheles gambiae* var. *melas* is found. The specimens in the writer's collection were obtained from a laboratory colony started by Dr. Henry Gelfand at the Liberian Institute for Medical Research from *C. thalassius* found in the neighbourhood.

Culex (C.) pipiens fatigans Wiedemann.

LOCALITIES. Monrovia ("common in July") (Bequaert, 1930); Harbel (ix).

HABITS. A common domestic pest where it occurs. The writer's examples of this species also were obtained from a laboratory colony started by Dr. Gelfand.

Culex (C.) decens Theobald.

LOCALITIES. Du group (Barber, Rice & Brown, 1932).

HABITS. Barber found the adults in dwellings. He recorded that some of these specimens were *C. decens* var. *invidiosus* Theo. This variety has now been

separated as a species but Edwards (1941) notes that specimens earlier identified thus may in fact be *C. invidiosus* var. *vevillatus* Edw. or entirely different species.

Culex (C.) invidiosus Theobald.

LOCALITIES. ? Du group (Barber, Rice & Brown, 1932); Kpain, Ganta, Dubuyi (iii, iv, v, vi, x), Baila (x).

HABITS. Larvae were found in various kinds of ground pools including roadside ditches with turbid, stagnant water; disused brick pits with clear, chalky water; a small pool with clear, straw-coloured water at pH 7.5; turbid swamp water near the St. John River containing much vegetation; a disused well with clear water and floating debris. In several of these sites, all of which were completely exposed to the sun, larvae of *Anopheles gambiae* were also present. A number of adults were taken on some swampy ground in April and a single male indoors at night in May.

Culex (C.) perfuscus Edwards.

LOCALITIES. Kpain (iv), Zugoli (vi).

HABITS. Larvae only were taken but the breeding places were not noted.

Culex (C.) telesilla De Meillon & Lavoipierre.

LOCALITIES. Zuluye (vi).

HABITS. Larvae were found in very stagnant water in an old stream bed together with those of *A. gambiae*.

TAXONOMIC NOTE. This species is very similar to *C. perfuscus*. The identification of the Liberian material is based on larvae only, of which the two recorded here are clearly *C. telesilla*, one is certainly *C. perfuscus* and the rest are not definitely assignable but have been included under *C. perfuscus*.

Culex (C.) perfidiosus Edwards.

LOCALITIES. Zugoli (vi).

HABITS. A single larva was found in a grassy pool formed in a ditch, together with larvae of *Aedes tarsalis*.

Culex (C.) guiarti Blanchard.

LOCALITIES. Du group (Barber, Rice & Brown, 1932); Robertsfield, Harbel (Briscoe, 1950); Kpain (iii, iv, v, vi, viii).

HABITS. The larvae of this species were found in various types of ground pool, usually with clear water exposed to the sun and with little vegetation. Pools formed by the overflow of streams in the rainy season are favoured. Briscoe found the adults in an abandoned wooden building near the breeding sites.

TAXONOMIC NOTE. In the Kpain larvae the lateral seta of the saddle is very short, $1/5-1/3$ as long as the saddle and 2-4 branched. The adults are of the typical form.

Culex (C.) ingrami Edwards.

LOCALITIES. Common over most of the project area all the year.

HABITS. The larvae may be found in most kinds of temporary ground pools, ditches and drains containing fairly fresh water.

TAXONOMIC NOTE. Three types of larvae have been described:—

a. The typical form with long siphon (index 11–14), 3 pairs of short subventral tufts, mentum (in Liberian specimens) with 13 teeth.

Distribution.—Sunyani, Gold Coast; Matadi, Belgian Congo; Nigeria; Kpain, Liberia.

b. Intermediate form with shorter siphon (index 8–10), 3 pairs of short subventral tufts, pecten extending the whole length of the siphon, mentum not recorded.

Distribution.—Kampala, Uganda; Matadi, Belgian Congo; S. Nigeria.

c. Short-siphoned form (index 5–7), 4 or 5 pairs of subventral tufts equal to or greater than the diameter of the siphon, mentum with 15 teeth.

Distribution.—Gaboon; Kpain, Liberia.

The genitalia of males reared from type *a* have the paraproct arm inconspicuous or absent, and the outer division of the phallosome is poorly developed with a short inner arm as illustrated by Edwards (1941).

Uganda males have a definite arm on the paraproct and larger processes on the outer division of the phallosome, including a scoop-like lateral process not well shown in Edwards' illustration.

Matadi specimens reared from mixed larvae of types *a* and *b* showed both types of genitalia.

Liberian specimens reared from type *c* have a still longer paraproct arm and the processes of the phallosome are also better developed though still within the same pattern. The spines and leaflets of the coxite lobe and the style are the same in all three forms.

Edwards regarded it as uncertain whether the different larval forms were correlated with the male genitalia forms. The evidence now seems to indicate that this correlation does exist, larval form *a* producing adult males with the least developed paraproct arm and phallosome, and type *c* the most developed. Larvae of types *a* and *c* and the genitalia of the corresponding males are very distinct and, seen together would suggest that the specimens are of two distinct species; but type *b* is intermediate in both larva and male genitalia. Although no intermediates were found between *a* and *c* in Liberia, Mattingly (personal communication) informs me that he did find intermediates between *a* and *b* in Nigeria. It seems preferable therefore, until more associated adults are reared from all three types of larvae, to consider them all as forms of a single species and not give them varietal names. Further evidence is also required on the geographical range of the different forms.

***Culex (C.) schwetzi* Edwards.**

LOCALITIES. Baila, Kpain (iii, iv).

HABITS. A series was reared from larvae found in abundance in rock pools in the middle of the St. John River at Baila, fully exposed to the sun and in company with *Aedes vittatus* and *Anopheles gambiae*. Other adults were reared from pupae found in a disused well together with larvae of *Uranotaenia chorleyi* and one of the *A. coustani* group. Other larvae were found in a borrow-pit.

TAXONOMIC NOTE. The larvae of *C. schwetzi* are very similar to those of *C. perfidiosus*. An account of them is included in Peters (1955b).

***Culex (C.) grahami* Theobald.**

LOCALITIES. Kpain, Baila (iv, vi), Buyi (x).

HABITS. Larvae were found in ground pools and in sand pits filled by the overflow of the St. John River in the rainy season. Others were found in clear ditch water together with larvae of the *C. bitaeniorhynchus* group.

Culex (C.) pruina Theobald.

LOCALITIES. Lengatown (viii), Paiata (x) (Bequaert, 1930); Kpain (iv, ix, x), Dubuyi (x).

HABITS. Bequaert recorded larvae at Lengatown "in a hole of a fallen tree in a forest clearing, together with those of *Culex decens* and *Lutzia tigripes*". We have found larvae in several types of water, from clear, chalky water in a shallow well and clean water in a larval breeding bowl, to foul greasy water in a small hole in the ground used for washing palm nuts. Adults were taken at rest in tree holes.

TAXONOMIC NOTE. Larval forms were found intermediate between the type form and var. *eschirasi* Galliard. In several specimens head seta d was 6-branched and in the rest 4-branched. The adults are atypical in that most of them have a small patch of up to a dozen flat white scales in the centre of the mesepimeron pointing caudally. Male genitalia of these are typical.

Culex (C.) moucheti Evans.

LOCALITIES. Robertsfield, Harbel (Briscoe, 1950); Yasono (ix).

HABITS. Briscoe found this species commonly in the coastal savannah, breeding in tree stumps and in permanent pools. He also captured adults in a stable trap and in an abandoned wooden building. Two larvae were found at Yasono in an old earthenware cooking pot filled with rain-water outside a native hut. The larvae hang perpendicularly in the middle of the water like those of *Aedes longipalpis*.

TAXONOMIC NOTE. The Liberian larvae differ slightly from the description in Hopkins (1952) as follows:—

Dorsal seta on abdominal segment IV double; seta B of segment VIII 6-branched; upper caudal seta with 8 branches; lateral seta of saddle with 2 branches on one side, 3 on the other.

Summary.

The results of a general mosquito survey of the Liberian hinterland are presented together with the findings of previous workers in this country.

Liberia is almost entirely in the Upper Guinean Forest region with an annual rainfall from over 140 in. on the coast to about 80 in. in the hinterland.

A list is given of all species recorded from Liberia.

A brief account is given of the distribution, bionomics and relation to malaria of the Anophelini, with some taxonomic notes. Thirteen species or forms of Anophelines are listed, of which ten were found in the hinterland as well as on the coast.

A summary of the distribution and bionomics of the Megarhinini and Culicini of Liberia is given, with the writer's field notes and those of earlier workers, and some taxonomic notes. Seventy one or 72 species or forms are included, of which 59 were found in the hinterland. If the first mention of some species in the two previous papers in this series be included, 41 additions to the Liberian list, three of them new species, have been made.

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References.

- BARBER, M. A., RICE, J. B. & BROWN, J. Y. (1932). Malaria studies of the Firestone rubber plantation in Liberia, West Africa.—*Amer. J. Hyg.*, **15**, pp. 601–633.
- BEQUAERT, J. (1930). Medical and economic entomology.—*In* Strong, R. P. *Ed.* The African Republic of Liberia and the Belgian Congo, **2**, pp. 797–1001. — Cambridge, Mass., Harvard Univ. Pr.
- BRISCOE, M. S. (1948). Insect reconnaissance in Liberia, West Africa.—*Psyche*, **54**, pp. 246–255.
- BRISCOE, M. S. (1950). Field notes on mosquitoes collected in Liberia, West Africa.—*Mosq. News*, **10**, pp. 19–21.
- BRISCOE, M. S. (1952). The relation of insects and insect-borne diseases to the vegetation and environment in Liberia.—*Ecology*, **33**, pp. 187–214.
- CHAPIN, J. P. (1932). The birds of the Belgian Congo. Part I.—*Bull. Amer. Mus. nat. Hist.*, **65**, 756 pp.
- CHWATT, L. J. (1945a). Studies on the melanic variety of *Anopheles gambiae* in southern Nigeria.—*J. trop. Med. Hyg.*, **48**, pp. 22–30, 51–55.
- CHWATT, L. J. (1945b). The morphology of the pharyngeal armature in *Anopheles gambiae* and *Anopheles gambiae* var. *melas* from southern Nigeria.—*Ann. trop. Med. Parasit.*, **39**, pp. 124–128.
- CHWATT, L. J. (1949). *Aedes* (*Stegomyia*) *pseudoafricanus* sp. nov.: a new species of *Aedes* from the coast of Nigeria (British West Africa).—*Nature*, Lond., **163**, pp. 808–809.
- DE MEILLON, B. (1947). The Anophelini of the Ethiopian geographical region.—*Publ. S. Afr. Inst. med. Res.*, no. 49, 272 pp.
- DE MEILLON, B. & LAVOPIERRE, M. (1944). New records and species of biting insects from the Ethiopian Region.—*J. ent. Soc. sthn Afr.*, **7**, pp. 38–67.
- DE MEILLON, B., PARENT, M. & BLACK, L. O'C. (1945). Descriptions of new larvae and pupae of Ethiopian Culicini.—*Bull. ent. Res.*, **36**, pp. 85–101.
- EDWARDS, F. W. (1941). Mosquitoes of the Ethiopian Region. III. Culicine adults and pupae.—499 pp. London, Brit. Mus. (Nat. Hist.).

- EVANS, A. M. (1932). Notes on African mosquitoes.—Ann. trop. Med. Parasit., **26**, pp. 85–108.
- EVANS, A. M. (1938). Mosquitoes of the Ethiopian Region. II. Anophelini, adults and early stages.—404 pp. London, Brit. Mus. (Nat. Hist.).
- GELFAND, H. M. (1954). The Anopheline mosquitoes of Liberia.—W. Afr. med. J., (N.S.) **3**, pp. 80–88.
- GELFAND, H. M. (1955). *Anopheles gambiae* Giles and *Anopheles melas* Theobald in a coastal area of Liberia, West Africa.—Trans. R. Soc. trop. Med. Hyg., **49**, pp. 508–527.
- GIBBINS, E. G. (1933). The domestic *Anopheles* mosquitoes of Uganda.—Ann. trop. Med. Parasit., **27**, pp. 15–25.
- HARLEY, G. W. (1939). Roads and trails in Liberia.—Geogr. Rev., **29**, pp. 447–460.
- HOLSTEIN, M. H. (1952). Biologie d'*Anopheles gambiae*. Recherches en Afrique-Occidentale Française.—Monogr. Ser. World Hlth Org., no. 9, 176 pp.
- HOPKINS, G. H. E. (1952). Mosquitoes of the Ethiopian Region. I. Larval bionomics of mosquitoes and taxonomy of Culicine larvae.—2nd edn., 355 pp. London, Brit. Mus. (Nat. Hist.).
- MATTINGLY, P. F. (1952). The sub-genus *Stegomyia* (Diptera, Culicidae) in the Ethiopian Region. I. A preliminary study of the distribution of species occurring in the West African sub-region with notes on taxonomy and bionomics.—Bull. Brit. Mus. (nat. Hist.), Ent. **2**, pp. 235–304.
- MATTINGLY, P. F. (1953). The sub-genus *Stegomyia* (Diptera: Culicidae) in the Ethiopian Region. II. Distribution of species confined to the East and South African sub-region.—Bull. Brit. Mus. (nat. Hist.), Ent. **3**, pp. 1–65.
- MATTINGLY, P. F. & CHWATT, L. J. BRUCE. (1954). Morphology and bionomics of *Aedes* (*Stegomyia*) *pseudoafricanus* Chwatt (Diptera, Culicidae), with some notes on the distribution of the subgenus *Stegomyia* in Africa.—Ann. trop. Med. Parasit., **48**, pp. 183–193.
- MUIRHEAD THOMSON, R. C. (1947). Recent knowledge about malaria vectors in West Africa and their control.—Trans. R. Soc. trop. Med. Hyg., **40**, pp. 511–536.
- MUIRHEAD THOMSON, R. C. (1948). Studies on *Anopheles gambiae* and *A. melas* in and around Lagos.—Bull. ent. Res., **38**, pp. 527–558.
- MUIRHEAD THOMSON, R. C. (1951). Mosquito behaviour in relation to malaria transmission and control in the tropics.—219 pp. London, Arnold.
- PETERS, W. (1955a). The mosquitoes of Liberia (Diptera: Culicidae).—Proc. R. ent. Soc. Lond., (B) **24**, pp. 81–90.
- PETERS, W. (1955b). The mosquitoes of Liberia (Diptera: Culicidae).—Proc. R. ent. Soc. Lond., (B) **24**, pp. 117–128.
- RIBBANDS, C. R. (1944). Differences between *Anopheles melas* (*A. gambiae* var. *melas*) and *Anopheles gambiae*. I. The larval pecten. II. Salinity relations of larvae and maxillary palp banding of adult females.—Ann. trop. Med. Parasit., **38**, pp. 85–86, 87–99.
- SCHWAB, G. (1947). Tribes of the Liberian hinterland.—Pap. Peabody Mus., **31**, 526 pp.

- VAN SOMEREN, E. C. C. (1949). Ethiopian Culicidae—*Eretmapodites* Theobald: description of four new species of the *chrysogaster* group with notes on the five known species of this group.—Proc. R. ent. Soc. Lond., (B) **18**, pp. 119–129.
- VAN SOMEREN, E. C. C. (1951). New Culicini from Kenya and Uganda.—Proc. R. ent. Soc. Lond., (B) **20**, pp. 1–9.
- STRONG, R. P. *Ed.* (1930). The African Republic of Liberia and the Belgian Congo . . . Volume I, pp. 12–31. Cambridge, Mass., Harvard Univ. Pr.
- YOUNG, M. D. & JOHNSON jr., T. H. (1949). A malaria survey of Liberia.—J. nat. Malar. Soc., **8**, pp. 247–266.
- ZIEMANN, H. R. P. (1902). Beitrag zur *Anopheles*-Fauna West-Afrikas. Vorläufige Mittheilung.—Arch. Schiffs- u. Tropenhyg., **6**, pp. 360–361.
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FIELD TESTS WITH LARVICIDES AGAINST *CULICOIDES* *IMPUNCTATUS* GOETGH. IN SCOTLAND.

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The annoyance caused to man by biting midges in Scotland is mainly due to one species, *Culicoides impunctatus* Goetgh. (Cameron & others, 1946). An attempt to reduce its density by barrier spraying was unsuccessful (Kettle, 1949) but these experiments yielded valuable data concerning the bionomics of *C. impunctatus*. In particular, it was found that the breeding sites were localised and that the midge density decreased rapidly with increasing distance from the breeding site. Seventy yards away the density was reduced to one-tenth its initial value; at 140 yards it was one-hundredth and at 210 yards it was one-thousandth (Kettle, 1951).

It should be possible, therefore, to eliminate *C. impunctatus* from any locality by neutralising all breeding sites within 200 yards. Before such a method can be applied it is necessary to be able to recognise breeding sites of *C. impunctatus* by macroscopic inspection—since the search for larvae is too tedious for practical purposes—and, having identified them, to render them unproductive. This can most readily be accomplished by the application of insecticides.

Larval control of *C. impunctatus* is particularly attractive as active larvae are to be found in the soil at all seasons of the year and the technique can therefore be carried out at any time convenient to the operator. Single small-plot (6 or 9 sq. yd.) field tests have been made against British *Culicoides* by Hill & Roberts (1947) and by Cameron (1948) who applied insecticides at the start of adult emergence. The widespread use of larval control will be severely limited if this period of application is critical and in these experiments sprays were applied during the autumn and winter.

Hill & Roberts (1947) obtained complete control of *C. impunctatus* by applying a miscible oil preparation of "Gammexane" at 100 mg./sq. ft. Their spraying was carried out at the end of a long dry spell and they found that under those conditions the larvicidal effect was enhanced by the subsequent rain. Cameron (1948) records the successful control of *C. pallidicornis* Kieff. by both

a "Gammexane" miscible oil and a DDT emulsion when applied at 200 mg./sq. ft. These dosages are very high (10 or 20 lb./acre) for economic control measures and it was hoped either that lower dosages would prove equally effective or that the greater expense of the higher dosages would be compensated by much longer residual action.

In the Western Caroline Islands, Dorsey (1947) found that diesel oil with or without the addition of 5 per cent. DDT was ineffective against the larvae of *C. peliliouensis* Tokunaga. This species breeds in the muddy margins of brackish tidal mangrove swamps and he attributed the failure to the absence of contact between larvae and insecticide. Ten per cent. DDT dust proved effective at 12–15 lb./acre (= 12–15 mg. DDT/sq. ft.) while DDT-xylene-Triton emulsion exercised control at about 4 oz. DDT/acre.

In the Bahamas, *C. furens* (Poey) breeds in similar situations to *C. peliliouensis*, and R. Hunt (The use of "Gammexane" in the control of the sandfly on the island of New Providence, Bahamas.—Unpublished report, Ross Institute, London, 1950) obtained satisfactory control by applying 10 per cent. "Gammexane" dust at 25 lb./acre (= 25 mg. γ BHC/sq. ft.). The same species has a nuisance value in the coastal districts of Florida where it has been studied for more than 20 years. Recent work there has shown that emulsions of dieldrin, chlordane, γ BHC, aldrin and heptachlor, all at 1 lb./acre (= 10 mg./sq. ft.), give excellent immediate control with variable residual action which in the case of dieldrin exceeded six months, but DDT gave poor control at 4 lb./acre (Goulding, Curran & Labrecque, 1953). Dieldrin and γ BHC on bentonite granules gave complete control for 24 and 12 weeks, respectively, in contrast to γ BHC oil solution which ceased to be effective after two weeks (Labrecque & Goulding, 1954).

The larvae of these tropical salt-marsh species live in the surface layers of mangrove and other coastal swamps and intimate contact is effected between them and water-miscible insecticides by tidal waters. Under water, larvae of

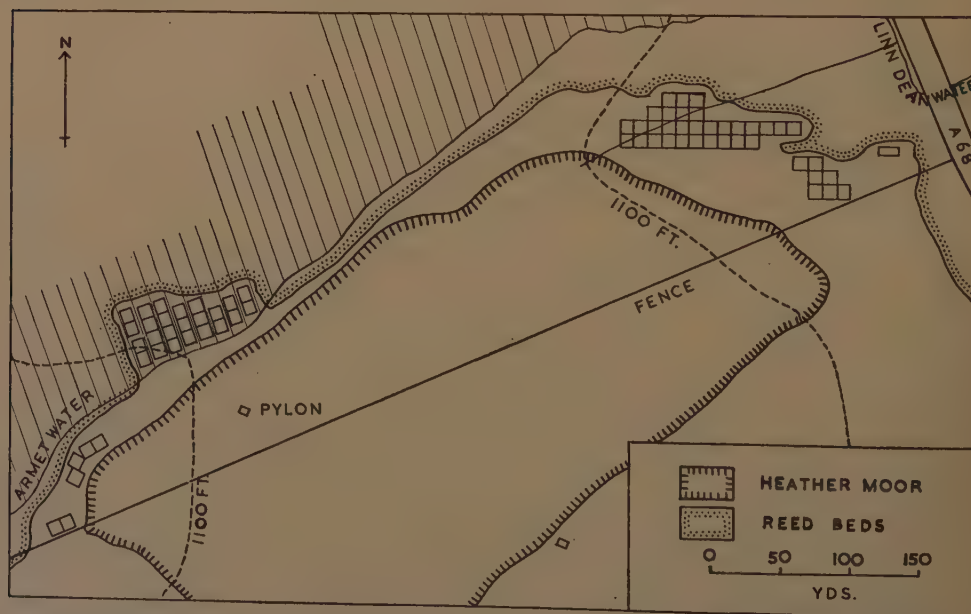


Fig. 1.—Experimental area on Soutra Hill. Small rectangle (top right) indicates position of preliminary experiment. Sites 1 and 2 are upper right and lower left, respectively.

C. furens (*C. dovei* Hall) become free-swimming and are redistributed at each spring tide (Dove, Hall & Hull, 1932). Although most larvae of *C. impunctatus* occur in the top inch of the soil (Kettle & Lawson, 1952) they are protected from insecticidal sprays by a layer of living moss, usually *Sphagnum* or *Polytrichum*, which may be six inches thick. In addition, they are never free-swimming and their habitat is so saturated with water that rain is as likely to wash insecticides away over the surface as to wash them into the soil. In contrast, tidal waters seep up through the soil from below.

This paper presents the results obtained with various insecticides in small-scale field trials. Two experiments were planned, the first to compare different preparations of DDT and γ BHC at selected dosages. In the second experiment some of the newer chlorinated hydrocarbon insecticides (dieldrin, aldrin, chlordane) were tested as well as malathion, an organic phosphorus compound which combines high insecticidal activity with low mammalian toxicity (Golz, 1952).

Description of Site.

The site chosen for these experiments lies about half a mile to the south of Soutra Hill at 1,100 feet above sea level, in the extreme south-east of the county of Midlothian where it joins Berwickshire and East Lothian. The potentially suitable area, shown in fig. 1, is situated on the watershed between Armet Water and Linn Dean Water, and extends over a distance of about half a mile from the main road (A68). An artificial drainage canal joins the head-waters of these streams which gives rise to fairly extensive beds of rushes of *Juncus* spp. Further south is an expanse of heather moor. Between these two, on either side of the watershed, lie the areas which preliminary sampling showed to be supporting a large population of larvae of *C. impunctatus*. The largest area, nearest the road, consists of an almost continuous cover of *Sphagnum* and *Scirpus* sp. *Polytrichum commune* and heather are abundant with *Sphagnum* in the more southerly part of this area, but they disappear northwards where species of grass are more common. To the south-east the flora is dominated by large tussocks of cotton grass, *Eriophorum vaginatum*, set amidst a ground cover of *Sphagnum*. The whole area is bounded to the north by *Juncus* beds and to the south by heather moor. Similar suitable areas of smaller extent are found between the heather moor and the Armet Water to the west of the watershed. On the north bank of the Armet Water, parallel drainage channels about 15 yards apart lead water into the main stream. This divides the ground into a series of narrow strips. Near the stream the vegetation consists largely of *Sphagnum* but between five and 40 yards distant from it *P. commune* becomes dominant. The mosses are interspersed with a sparse covering of *Juncus* and with small areas of drier grassland.

Soil Sampling.

To estimate the larval population, soil samples three inches in diameter were taken by means of a soil borer, and the top two inches of these examined. The material was washed through two sieves, mesh 10 and 20, by a strong jet of water, until all inorganic matter was removed, and the filtrate passed slowly through an 80-mesh sieve. The material retained was added to a concentrated solution of magnesium sulphate (Sp. Gr. 1.15–1.20) in a dish six inches in diameter. The inorganic material sank to the bottom, while the organic matter, including *Culicoides* larvae, rose to the surface. The search for larvae was facilitated by a low-power magnifier and the larvae were transferred to clear water for identification. This technique is believed to recover all fourth-, third- and second-stage larvae. After collection, samples were stored in an unheated room while awaiting washing, to avoid increasing their temperature which might

assist insecticidal action. They were washed within eight days of collection on each occasion. Very few dead or dying larvae were recovered during the work, indicating that this effect was reduced to a minimum.

Statistical Treatment.

The examination of soil samples is a slow and tedious process, taking about three quarters of an hour for each sample to be washed, the larvae removed and identified. Therefore it is important to reduce the number of samples to the minimum consistent with satisfactory statistical analysis of the results. For various practical reasons it was decided to examine nine samples from each plot (10 yd. \times 10 yd.) both before and after treatment. In the event, this number of samples (9) was shown to be adequate. This represented three months' work for two people on site 1 alone. In order to allow for any seasonal variation, three samples were removed from each plot on three separate occasions. The variation in larval density among samples taken from the same plots is large and it will be seen from Table I that by taking nine samples a difference of 67 per cent. is

TABLE I.

Relationship between the number of samples taken from each plot and the 5 per cent. significant difference between plot means ($t_{0.05S\bar{x}}$). The latter is also expressed as a percentage of the mean larval density for each site.

Number of samples	Site 1		Site 2	
	$t_{0.05S\bar{x}}$	Per cent. of site mean	$t_{0.05S\bar{x}}$	Per cent. of site mean
3	± 3.322	116	± 4.869	91
5	± 2.573	90	± 3.770	70
9	± 1.918	67	± 2.810	52
25	± 1.151	40	± 1.686	31
50	± 0.813	28	± 1.193	22
100	± 0.574	20	± 0.844	16

statistically significant ($P = 0.05$) on site 1, while on site 2 a difference of 52 per cent. is equally significant. These differences are large, but effective anti-larval measures should exert this degree of control. Even if nearly three times as many samples are examined, the difference between pre-treatment and post-treatment means must exceed 40 per cent. on site 1 and 31 per cent. on site 2 to be considered significant.

Notwithstanding the large variation within plots, there are highly significant differences between plots (Table II). Therefore it is not permissible to compare the larval densities of different plots directly but each must be compared with its own pre-treatment density.

There is evidence available that the larval distribution in the soil is correlated with the vegetative cover. For this reason sampling within plots was not entirely at random but randomised over the suitably vegetated areas.

Preliminary Experiment.

In order to obtain information regarding a suitable dose range, a small preliminary experiment was conducted. A small area (the rectangle nearest the road in fig. 1) with a similar flora to the larger area described was selected for

TABLE II.

Analyses of Variance of numbers of larvae of *C. impunctatus* in pre-treatment samples from site 1 (above) and site 2 (below).

Source of variance	Degrees of freedom	Sum of squares	Mean square	
Between plots	36	750.677	20.852	$F = 2.419$
Within plots	296	2551.113	8.619	$P < 0.001$
Total	332	3301.790		
Between plots	27	1001.250	37.083	$F = 2.028$
Within plots	224	4094.889	18.281	$P < 0.01$
Total	251	5096.139		

F = Variance ratio and P = Probability.

this purpose. It was divided into sixteen plots (2 yd. \times 2 yd.) and before treatment two soil samples were removed from each. A water-miscible concentrate was used for these experiments since it had been found effective by Hill & Roberts (1947) and Cameron (1948). Both DDT and γ BHC were used at seven dosages—3, 6, 12, 25, 50, 100 and 200 mg./sq. ft.—the necessary volume of concentrate being made up to half a pint with water, and applied with a small "Mysto" hand sprayer of two pints capacity. Treatment took place at the end of November 1953. Four samples were taken from each plot two weeks after treatment and the percentage control achieved is shown in Table III.

The results were difficult to interpret as the larval mortality did not increase with increasing dosage and one of the untreated plots had a reduction of 90 per cent. This failure may have been due in part to the small number of samples examined, to some plots being more sparsely populated than the pre-treatment sampling had suggested and to insecticidal contamination of adjacent plots by rain.

Comparison of p,p'DDT and γ BHC—Site 1.

Four formulations (dust, oil solution, wettable powder and water-miscible concentrate) of both DDT and γ BHC were tested against larvae of *C. impunctatus* on site 1. Each was applied at four dosages (3, 12, 50 and 200 mg. p,p'DDT or γ BHC/sq. ft.) with the exception of the "Gammexane" dust which had a very low γ BHC content and to avoid the application of an unwieldy volume of dust it was applied at 3, 6, 12 and 25 mg. γ BHC/sq. ft. The preparations used were:—

DDT.

Water-miscible concentrate, 25 per cent. technical DDT = 21.5 per cent. w/v p,p'isomer.

Oil solution, 25 per cent. technical DDT = 21.9 per cent. w/v p,p'isomer.

Wettable powder, 40 per cent. p,p'isomer.

Dust, 4 per cent. p,p'isomer.

γ BHC.

Water-miscible concentrate, 7.5 per cent. w/v γ BHC.

Oil solution, 8.3 per cent. γ BHC.

Wettable powder, 6.5 per cent. γ BHC.

Dust, 0.5 per cent. γ BHC.

The more easterly area (site 1) was divided into 37 plots (10 yd. \times 10 yd.), marked by 3-ft. stakes (fig. 1). It was estimated that about 10 per cent. of the site was unsuitable for sampling, either because it was too dry, with grass and

TABLE III.

Preliminary experiment. Differences, expressed as percentages of pre-treatment values, between pre-treatment and post-treatment larval densities of *C. impunctatus* two and eight weeks after spraying.

Dose mg./sq. ft.	Two weeks		Eight weeks	
	DDT		DDT	
	Per cent. + —	Per cent. + —	Per cent. + —	Per cent. + —
200	91	100	95	90
100	83	100	100	100
50	80	50	70	38
25	100	75	95	100
12	100	100	79	81
6	93	43	82	170
3	25	93	25	78
Untreated				
1	33		15	
2	90		63	

no *Sphagnum*, or was continually marshy. These parts were ignored and samples were distributed evenly throughout the rest of the plots. They were taken from the edges of clumps of *Sphagnum* or *Polytrichum* where the layer of moss was thin. Counts of the number of samples containing either of these mosses or both show that similar numbers of each type of sample were taken on each occasion. This is important if, as suggested earlier, larval density of *C. impunctatus* is correlated with the vegetative cover. The whole area was sampled on three occasions during November and December when three samples were taken from each plot.

The treatments were assigned to the plots as shown in fig. 2 with like dosages of DDT and γ BHC together, but otherwise the distribution was at random. Spraying took place two weeks before Christmas 1953, using a Four Oaks Knap-sack sprayer (capacity $3\frac{1}{4}$ gallons). Preliminary trials showed that good coverage of 100 sq. yards could be obtained by using 14 pints of liquid in the sprayer.

The wettable powders and dusts were weighed indoors and the former mixed with water on the experimental site. The water-miscible concentrates and oil solutions were measured by volume and diluted with water and paraffin, respectively, the total volume in each case being 14 pints. The residue was measured after the completion of each application and the actual dosage calculated; in

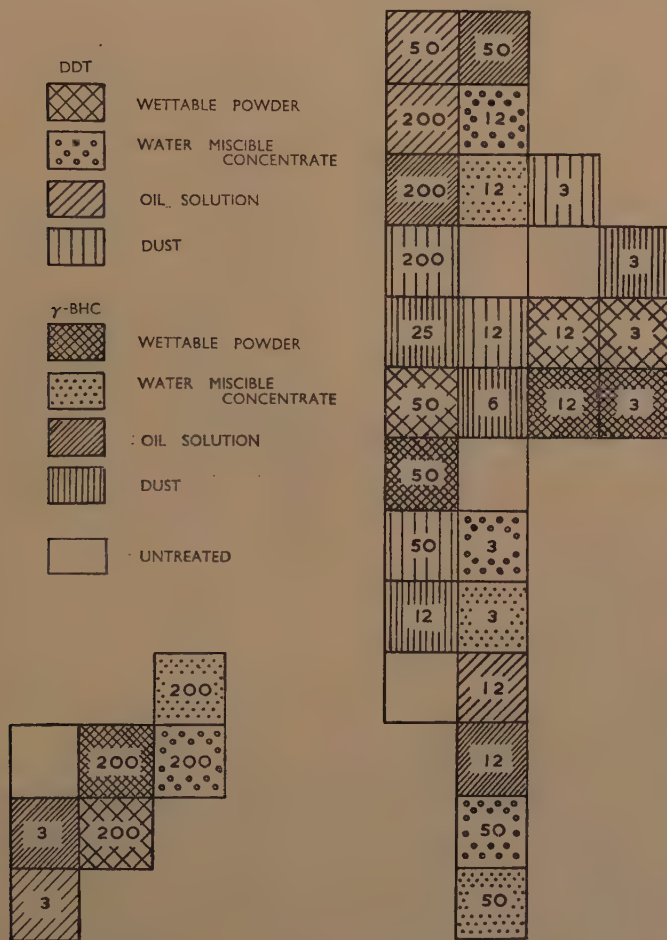


Fig. 2.—Arrangement of DDT and γ BHC treatments on Soutra site 1. Figures indicate dosage in mg./sq. ft.

each case the actual dosage fell below that intended by 3.7 to 7.6 per cent. The dusts were applied by means of a 40-mesh sieve to give as even a cover as possible. Spraying took place under ideal conditions on dry days with little or no wind. The water-miscible concentrates and wettable powders were visible as white deposits for a few days only but the dusts were discernible on the surface for about one month.

It was anticipated that the action of the insecticides would proceed slowly during the winter months and samples were taken about a month after spraying. During the 24 days which elapsed between the completion of spraying and the first post-treatment sampling, there were nine wet days and a total of 0.93 inches

TABLE IV.

Numbers of larvae of *C. impunctatus* found on sampling plots before and after DDT treatment and untreated plots.

Treat- ment	Dosage mg/ sq. ft.	Before treatment				After treatment				Per cent. difference + —	After summer				Per cent. difference + —		
		7.xi.53	20.xi.53	30.xi.53	Total	15.i.54	21.ii.54	31.iii.54	1.v.54		Total	6.xi.54	28.xi.54	15.i.55		Total	
Wettable powder	3	5	10	5	20	14	1	9	10	34	28	40	6	4	2	12	68
	12	7	11	2	15	12	1	0	11	24	20	80	3	0	0	3	96
	50	14	7	6	27	3	1	2	3	9	75	96	1	0	0	1	100
	200	16	3	9	28	3	0	1	2	6	84	100	0	0	0	0	100
Oil solution	3	22	6	10	38	10	0	11	21	42	17	40	29	22	13	64	68
	12	21	12	22	55	34	10	12	49	105	43	96	0	0	2	2	96
	50	1	5	8	14	29	2	17	5	53	184	78	2	0	1	3	78
	200	2	2	5	9	0	2	12	4	18	50	45	1	3	1	5	45
Water- miscible concen- trate	3	22	29	18	69	17	5	17	34	73	21	93	46	24	14	84	22
	12	6	0	9	15	4	5	4	9	22	10	93	0	0	1	1	93
	50	24	3	15	42	9	7	3	4	23	59	95	0	1	1	2	95
	200	11	4	13	28	0	2	0	0	2	95	100	0	0	0	0	100
Dust	3	11	4	7	22	11	12	36	16	75	156	93	16	14	14	44	100
	12	6	8	1	15	11	17	3	0	31	55	90	0	0	1	1	93
	50	9	2	9	20	7	1	2	3	13	51	90	2	0	0	2	90
	200	24	5	13	42	14	7	19	7	47	16	98	1	0	0	1	98
Untreated	3	13	3	5	21	20	16	5	9	50	79	76	3	1	1	5	76
	12	7	4	9	20	23	7	22	7	59	122	70	16	6	12	34	70
	50	10	5	0	15	14	5	17	11	47	135	367	27	19	24	70	367
	200	11	9	10	30	4	7	22	11	44	10	83	20	6	29	55	83
		5	1	8	16	23	13	5	6	47	120	238	7	31	16	54	238

Each sampling consisted of three samples.

TABLE V.

Numbers of larvae of *C. impunctatus* found on sampling plots before and after γ BHC treatment.

Treat- ment	Dosage mg./ sq. ft.	Before treatment			After treatment					Per cent. difference + —	After summer				Per cent. difference + —
		7.xi.53	20.xi.53	30.xi.53	Total	15.i.54	21.ii.54	31.iii.54	1.v.54		6.xi.54	28.xi.54	15.i.55	Total	
Wettable powder	3	2	2	22	26	20	0	12	8	40	27	31	29	87	235
	12	5	9	5	19	10	7	13	8	38	4	5	5	14	26
	50	8	4	10	22	0	9	1	1	11	1	2	0	3	86
	200	14	0	6	20	2	0	0	0	2	0	0	0	0	100
Oil solution	3	15	4	15	34	20	41	27	11	99	46	34	25	105	209
	12	7	6	18	31	7	3	1	8	19	5	20	10	35	13
	50	8	5	14	27	8	4	13	27	52	9	21	11	41	52
	200	2	4	3	9	8	1	12	3	24	6	13	0	19	111
Water- miscible concen- trate	3	10	25	23	58	10	11	23	21	65	31	33	29	93	60
	12	5	6	7	18	13	24	8	20	65	33	22	16	71	294
	50	21	3	14	38	27	12	23	24	86	18	11	17	46	21
	200	12	0	6	18	7	0	0	0	7	0	0	1	1	94
Dust	3	5	3	5	13	28	3	21	5	57	13	11	26	50	285
	6	9	6	7	22	13	12	21	14	60	29	11	26	66	200
	12	8	1	2	11	5	3	16	11	35	22	7	4	33	200
	25	4	12	6	22	9	12	18	4	43	8	7	2	17	23

Each sampling consisted of three samples.

of rain was recorded. Three more samplings were made at monthly intervals giving a total of 12 samples per plot after treatment. When sampling after treatment, care was taken to sample the untreated plots first and the dosages of DDT and γ BHC in ascending order. This would minimise any transference of insecticide from the heavily dosed samples during storage. It was hoped that the effect of the treatments would persist during the summer and prevent the re-colonisation of the plots during the active season of the midge. To assess this effect, the area was sampled three times at approximately monthly intervals during the autumn, starting one year after the first pre-treatment sampling.

Immediate effect.

The larval densities are recorded in Tables IV and V, in which the numbers of larvae of *C. impunctatus* found at each sampling are entered. For convenience, the readings for individual samples have been omitted although they were the basis of the statistical analysis. In Table VI, the mean numbers of larvae per sample before and after treatment are compared. Rather unexpectedly, all the untreated plots showed increases in larval density ranging from 10 per cent. to 135 per cent. and in four out of the five untreated plots these increases were significant. The explanation of this is not clear, but it is considered unlikely to be due to the migration of larvae away from the treated plots. Large increases

TABLE VI.

Mean number of larvae of *C. impunctatus* per sample for each treatment.

Formulation	Dose mg./sq. ft.	DDT			γ BHC		
		Before treatment	After treatment	After summer	Before treatment	After treatment	After summer
Wettable powder	3	2.2	2.8	1.3	2.9	3.3	***9.7
	12	1.7	2.0	0.3	2.1	3.2	1.6
	50	3.0	0.8*	0.1**	2.4	0.9	0.3*
	200	3.1	0.5**	0.0**	2.2	0.2*	0.0*
Oil solution	3	4.2	3.5	**7.1	3.8	***8.3	***11.7
	12	6.1	8.7	0.2***	3.4	1.6*	3.9
	50	1.6	**4.4	0.3	3.0	4.3	4.6
	200	1.0	1.5	0.6	1.0	2.0	2.1
Water- miscible concentrate	3	7.7	6.1	9.3	6.4	5.4	***10.3
	12	1.7	1.8	0.1	2.0	***5.4	***7.9
	50	4.7	1.9**	0.2***	4.2	**7.2	5.1
	200	3.1	0.2**	0.0**	2.0	0.6	0.1*
Dust†	3	2.4	***6.2	**4.9	1.4	***4.7	***5.6
	12	1.7	2.6	0.1	2.4	**5.0	***7.3
	50	2.2	1.1	0.2*	1.2	2.9	**3.7
	200	4.7	3.9	0.1***	2.4	3.6	1.9
Untreated		2.3	*4.2	0.6			
		2.2	**4.9	3.8			
		1.7	*3.9	***7.8			
		3.3	3.7	**6.1			
		1.8	*3.9	***6.0			

Three values are given—before and after spraying and after a full season of adult activity. Significant differences are marked by asterisks to the right for decreases and to the left for increases. *, **, and *** indicate probabilities of less than 0.05, 0.01 and 0.001, respectively. † = γ BHC dosages 3, 6, 12 and 25 mg./sq. ft.

are also to be found in most of the plots treated with dusts or oil solutions, two preparations which appear to have little immediate larvicidal action. Further evidence that this increase is not due to a redistribution of the larvae is afforded by the fact that the overall larval density increases by 21 per cent. and it can hardly be anticipated that all the larvae which disappeared from the treated plots made their way to the untreated ones. Consideration of this and other features of the larval ecology will be reserved for a later paper. On pooling the data from the untreated plots the increase between pre-treatment and post-treatment larval densities is 82 per cent. This must be considered in assessing the degree of control achieved by insecticidal treatment.

With the DDT treatment, highly significant reductions in larval densities were obtained by applications of 50 and 200 mg./sq. ft. as a wettable powder or a water-miscible concentrate, while the DDT dust exerted slight control at the same dosages but the oil solution was ineffective.

The results with γ BHC were surprising for the ineffectiveness of the water-miscible concentrate preparation in all except the highest dosage. The wettable powder produced rather better results at both 50 and 200 mg./sq. ft. The oil solution had little larvicidal effect except for an "aberrant" reading for 12 mg./sq. ft. When large numbers of comparisons are being made, as in the present series of tests, it is to be anticipated that there will be an occasional "aberrant" result. On the average, in the 37 tests being made here, the 5 per cent. level of significance can be exceeded twice without indicating any deviation from normality. The "Gammexane" dust was completely ineffective at the dosages tried—25 mg./sq. ft. and lower.

Further information can be obtained by pooling all the data for each dosage and each formulation separately (Table VII). From this it will be seen that the most successful formulation is DDT water-miscible concentrate with the DDT

TABLE VII.

Effect of formulation and dosage of DDT and γ BHC on larval density of *C. impunctatus*, represented by mean number of larvae per sample.

Formulation or dosage mg./sq. ft.	DDT			γ BHC		
	Before treatment n=36	After treatment n=48	After summer n=36	Before treatment n=36†	After treatment n=48††	After summer n=36†
Wettable powder	2.50	1.52*	0.44***	2.42	1.90	2.89
Oil solution	3.22	**4.54	2.05*	2.81	**4.04	***5.55
Water-miscible concentrate	4.28	2.50***	2.42***	3.67	*4.65	***5.86
Dust	2.75	3.46	1.33**	1.88	***4.06	***4.61
3	4.14	4.67	**5.69	3.64	***5.44	***9.31
12	2.78	*3.79	0.19***	2.19	*3.27	***4.25
50	2.86	2.04	0.22***	3.22	4.14	3.33
200	2.97	1.52**	0.17***	1.74	0.92*	0.74

n = number of samples. † and †† indicate n = 27 and 36, respectively, for dosages of 50 and 200 mg./sq. ft. For untreated results see Table IX. Other symbols as in Table VI.

wettable powder also producing a significant reduction in larval density. None of the γ BHC formulations was effective as a larvicide and indeed in all except the wettable powder the larval density increased significantly. As regards dosage, only the highest application (200 mg./sq. ft.) achieved a significant degree of control.

Appreciation of these results is hampered by the increase in larval density in the untreated plots. In Table VIII the percentage control has been calculated for each dosage and preparation after increasing the pre-treatment larval density by 82 per cent. as in the untreated plots. The picture then becomes clearer.

TABLE VIII.

Percentage control achieved by various formulations and dosages of DDT and γ BHC.

Formulation or dosage mg./sq. ft.	DDT		γ BHC	
	Immediate control	Residual control	Immediate control	Residual control
Wettable powder	67	92	57	44
Oil solution	23	70	21	7
Water-miscible concentrate	68	74	30	25
Dust	31	77	Nil	Nil
3	38	36	18	Nil
12	25	97	18	9
50	61	96	29	52
200	72	97	71	80
All treatments	48	77	25	18
All treatments excluding dust	53	77	35	25

The figures have been adjusted for the 82 per cent. and 114 per cent. increases found in the untreated plots after spraying and after the summer, respectively.

DDT wettable powder and water-miscible concentrate are equally effective and both slightly more successful than the γ BHC wettable powder but the γ BHC water-miscible concentrate was relatively ineffective. DDT at 50 mg./sq. ft. and either DDT or γ BHC at 200 mg./sq. ft. appear to be suitable dosages for immediate larval control.

DDT is superior to γ BHC at all dosages and in all formulations (Tables VIII & IX). This is indicated also when all the treatments are pooled. For accurate comparison the results for γ BHC dust must be omitted as it was applied at lower dosages.

Residual effect.

After a full season of adult activity, the experimental plots were resampled to determine whether the treatments persisted long enough to have an effect on the next generation of *C. impunctatus*. The results obtained were much more consistent and therefore easier to interpret (Tables IV-VI). In spite of an increase

in larval density of 114 per cent. in the untreated plots, nine of the 16 DDT treatments produced larval reductions of 90 per cent. or more. DDT wettable powder was the most successful preparation, achieving marked larval reduction (>40 per cent.) at all dosages. The other three preparations were effective at all but the lowest dosage (3 mg./sq. ft.). DDT water-miscible concentrate obtained over 90 per cent. control at dosages of 12 mg./sq. ft. and over. A surprising result

TABLE IX.

Mean larval density of *C. impunctatus* per sample in untreated plots and those treated with either DDT or γ BHC.

Treatment	Before treatment		After treatment		After summer	
	n	Mean	n	Mean	n	Mean
DDT all treatments	144	3.19	192	3.01	144	1.56***
γ BHC all treatments	144	2.69	192	***3.66	144	***4.74
DDT excluding dust	108	3.33	144	2.85	108	1.64***
γ BHC excluding dust	108	2.96	144	*3.53	108	***4.77
Untreated	45	2.27	60	***4.12	45	***4.84

n = number of samples. Other symbols as in Table VI.

was the big larval reduction brought about by the application of DDT dust at dosages of 12 mg./sq. ft. or more. The DDT oil solution was inconsistent in its results, achieving a highly significant reduction (Table VI) at 12 mg./sq. ft. but becoming less effective with increasing dosage. In short, DDT demonstrated highly significant residual effect at dosages of 12 mg./sq. ft. or more (Tables VII & VIII), while each of the four preparations achieved at least a significant degree of control, and of these the wettable powder was the most effective.

The γ BHC results were disappointing, as the only effective treatments were γ BHC wettable powder at all except the lowest dosage and the highest dosages of the water-miscible concentrate (200 mg./sq. ft.) and the dust (25 mg./sq. ft.). The other treatments are remarkable for large increases in larval densities which, in six of the eleven, were highly significant, equalling or exceeding 200 per cent. Only the γ BHC wettable powder is comparable to its corresponding DDT preparation and even here the γ BHC product is less successful at all dosages except the highest. For residual effect DDT is very much superior to γ BHC (Table IX).

Comparison of Dieldrin, Aldrin, Chlordane and Malathion—Site 2.

This experiment was planned early in 1954 when the first results of the previous experiment were becoming available. These indicated that the wettable powders were the most effective formulation tried, and therefore dieldrin, aldrin and malathion were obtained in this form. Malathion was also readily available as an emulsifiable liquid and this was included in the trials. Chlordane, being a liquid, is more easily formulated as a water-miscible concentrate and was applied as such. DDT and γ BHC wettable powders, used earlier, were included in the trial for comparison with these insecticides and with the earlier results. It was

thought possible that the insecticides would act more rapidly in the comparatively warmer weather and produce a greater degree of control.

DDT and γ BHC were applied at 12 and 50 mg./sq. ft. as there was little doubt at that time that they were useless at 3 mg. and effective at 200 mg./sq. ft. The dosages of the other compounds were decided with reference to their toxicity to other insects. Dieldrin and aldrin were applied at 3, 6, 12 and 25 mg./sq. ft.; chlordane at 6, 12, 25 and 50 mg./sq. ft. In order to test two formulations of malathion it was only possible, for practical reasons, to use three dosages, 3, 12 and 50 mg./sq. ft. The actual dosages applied were about 6 per cent. lower than intended.

The materials used were:—dieldrin wettable powder, 10 per cent. by weight; aldrin wettable powder, 22.3 per cent. by weight; chlordane water-miscible concentrate, 55 per cent. w/v; malathion emulsifiable liquid, 60 per cent. w/v; malathion wettable powder, 25 per cent. by weight.

The suitable areas to the west of site 1 were divided into plots 10 yd. by 10 yd., 24 being arranged in strips between the drainage channels, while the rest were placed between the Armet Water and the heather moor (fig. 1). The area was sampled three times at fortnightly intervals, giving a total of nine samples before treatment. The results from these samples showed that some plots were only sparsely populated, or only populated in small patches, and therefore in four cases two adjacent plots were combined. These pairs received identical treatment and were sampled as a single unit after spraying. Of the total area within the plots the percentage unsuitable for sampling was 16 per cent. These unsuitable

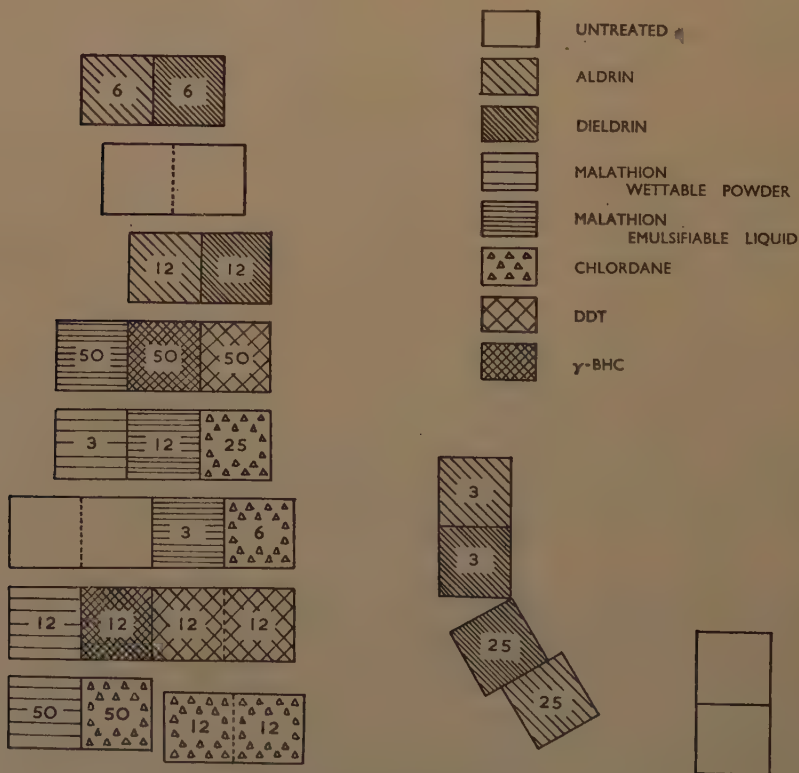


Fig. 3.—Arrangement of treatments on Soutra site 2.
Figures indicate dosage in mg./sq. ft.

TABLE X.

Numbers of larvae of *C. impunctatus* found on sampling plots in site 2 before and after treatment.

Treat- ment	Dosage mg./ sq. ft.	Before treatment			After treatment			Per cent. difference +	After summer			Per cent. difference +		
		10.iii.54 17.iii.54 23.iii.54			12.v.54 19.v.54 26.v.54				16.xi.54 8.xii.54 28.i.55					
		Total	Total	Total	Total	Total	Total		Total	Total	Total			
Dieldrin	3	16	16	9	41	8	20	11	39	4	8	4	16	61
	6	12	13	24	49	7	10	18	35	3	6	1	10	80
	12	12	13	19	44	15	8	19	42	10	9	5	24	45
	25	29	16	27	72	17	12	20	49	2	3	3	8	89
Aldrin	3	37	29	22	88	36	12	32	80	25	16	23	64	27
	6	26	4	25	55	3	18	14	35	28	7	16	51	7
	12	13	18	45	76	6	18	10	34	37	14	20	71	7
	25	18	16	15	49	5	6	22	33	28	7	2	37	24
Chlordane	6	30	25	23	78	14	32	10	56	20	16	6	42	46
	12	23	19	6	48	9	4	10	23	16	4	6	26	46
	25	11	22	27	60	13	20	14	47	13	19	3	35	42
	50	5	2	31	38	4	10	7	21	4	3	6	13	66
Malathion wettable powder	3	7	10	26	43	1	5	7	13	26	9	19	54	26
	12	8	8	18	34	6	7	9	22	13	5	14	32	6
	50	35	9	14	58	4	8	10	22	8	18	10	36	38
Malathion emulsifiable liquid	3	16	17	12	45	7	4	12	23	17	15	14	46	2
	12	13	10	7	30	4	4	2	10	37	37	18	92	207
	50	18	25	13	56	4	11	14	29	30	14	8	52	7
DDT	12	15	3	10	28	4	1	24	29	14	4	2	20	29
	50	9	12	15	36	15	11	13	39	1	0	0	1	97
γ BHC	12	25	11	22	58	15	2	12	29	7	4	6	17	71
	50	8	22	16	46	11	24	8	43	0	0	2	2	96
Untreated		26	16	21	63	17	7	18	42	30	9	32	71	13
		6	4	6	16	1	8	5	14	13	11	22	46	188
		10	8	11	29	32	6	14	52	9	11	36	56	93
		27	15	17	59	41	22	19	82	31	37	30	98	66

Each sampling consisted of three samples.

areas were not evenly distributed, being more or less absent from 11 plots but forming about 34 per cent. of the combined plots.

The dominant vegetation of the samples taken on each occasion was recorded and it was shown that, in keeping with the earlier description of this site, more samples contained *Polytrichum* and less contained *Sphagnum* than on the first site. There was also a greater variation in the types of samples taken on different occasions.

The arrangement of treatments on this site is shown in fig. 3. Similar doses of dieldrin and aldrin were applied to adjacent plots and the other compounds either in groups of like dose or in groups of ascending dosage down the slope, thus minimising the effect of contamination by insecticides washed downhill. Of the untreated plots, two were suitably placed among the rest but the other two were isolated from the rest of the site to avoid all risk of contamination.

It was intended that this area should be sprayed during the first week of April, but only the DDT, γ BHC and the two lower doses of chlordane were applied then owing to the frequent strong winds. The spraying was completed after an interval of 17 days during which only 0.02 inches of rain fell. Spraying took place on calm overcast days. During the 15 days which elapsed between

TABLE XI.

Mean number of larvae of *C. impunctatus* per sample for each treatment.

Insecticide	Dosage mg./sq. ft.	Before treatment	After treatment	After summer
Dieldrin wetable powder	3	4.6	4.3	1.8*
	6	5.4	3.9	1.1**
	12	4.9	4.7	2.7
	25	8.0	5.4	0.9***
Aldrin wetable powder	3	9.8	8.9	7.1
	6	6.1	3.9	5.7
	12	8.4	3.8**	7.9
	25	5.4	3.7	4.1
Chlordane water- miscible concentrate	6	8.7	6.2	4.7**
	12	5.3	2.6	2.9
	25	6.7	5.2	3.9*
	50	4.2	2.3	1.4*
Malathion wetable powder	3	4.8	1.4*	6.0
	12	3.8	2.4	3.6
	50	6.4	2.4**	4.0
Malathion emulsifiable liquid	3	5.0	2.6	5.1
	12	3.3	1.1	***10.2
	50	6.2	3.2*	5.8
DDT wettable powder	12	3.1	3.2	2.2
	50	4.0	4.3	0.1**
γ BHC wettable powder	12	6.4	3.2*	1.9**
	50	5.1	4.8	0.2***
Untreated		7.0	4.7	7.9
		1.8	1.6	*5.1
		3.2	5.8	*6.2
		6.6	9.1	**10.9

See Table VI for meaning of symbols used.

the completion of spraying and the first post-treatment sampling, a total of 3.58 inches of rain fell on eight days.

After spraying, the area was sampled three times during May, before the emergence of adults, giving a total of nine samples from each plot after treatment. Care was taken to avoid contamination between samples by storing those treated with different insecticides separately. As earlier, the residual effect was assessed by three samplings made at monthly intervals during the following autumn.

Immediate effect.

The results of the before and after treatment samplings are given in Table X. On site 2 the larval density in the untreated plots changed from 4.64 to 5.28 larvae per sample, an increase of 14 per cent., which is not significant. This simplifies the task of assessing the degree of control obtained. Leaving aside the DDT and γ BHC results for consideration later, the first striking fact is that all the insecticides have produced a reduction in larval density at all dosages. These reductions are statistically significant for three dosages of malathion, one of aldrin but none of chlordane or dieldrin (Table XI). When the results for each insecticidal preparation are pooled, emphasis is placed upon consistency, and the chlordane results now become highly significant, but those for dieldrin only approach a value of $P = 0.1$ (Table XII). The two malathion preparations

TABLE XII.

Mean larval density of *C. impunctatus* per sample before and after treatment with various insecticides and again after the summer period of adult activity.

Treatment	Number of samples	Before treatment	After treatment	After summer	Percentage control	
					Immediate	Residual
Untreated	36	4.64	5.28	***7.53	+14	+62
Dieldrin	36	5.72	4.58	1.61***	—20	—72
Aldrin	36	7.44	5.06**	6.19	—32	—17
Chlordane	36	6.22	4.08**	3.22***	—34	—48
Malathion wettable powder	27	5.00	2.11***	4.52	—58	—10
Malathion emulsifiable liquid	27	4.85	2.30**	**7.04	—53	+45
DDT	18	3.55	3.78	1.17*	+6	—67
γ BHC	18	5.78	4.00	1.06***	—31	—82

For symbols see Table VI.

are the most effective larvicides, as both achieve a reduction of over 50 per cent., the reduction with chlordane and aldrin is a little over 30 per cent., and with dieldrin only 20 per cent.

A noticeable feature of Table X is the complete lack of correlation between the insecticidal dosage applied and the larval reduction. Thus, both preparations of malathion attain the same degree of control at the weakest and strongest

dosages in spite of a 17-fold increase in insecticidal concentration. The same feature is to be noted with the other insecticides and it is confirmed in Table XIII. where the results for each dosage have been pooled. This is illustrated in fig. 4, and suggests that larval mortality is limited by a factor which is independent of

TABLE XIII.

Effect of dosage, irrespective of insecticide, on larval density of *C. impunctatus* (excluding results for DDT and γ BHC).

Dosage mg./sq. ft.	Number of samples	Before treatment	After treatment	After summer	Percentage control	
					Immediate	Residual
3	36	6.03	4.31*	5.00	29	17
6	27	6.74	4.67*	3.81***	31	43
12	45	5.16	2.91***	5.44	44	Nil
25	27	6.70	4.78*	2.96***	29	56
50	27	5.63	2.67***	3.74*	53	34

For symbols see Table VI.

the concentration of insecticide. One feature constant to all treatments was the volume of fluid in which the insecticide was applied but this condition also operated in the first experiment. Here too the mortalities obtained by low dosages (3 and 12 mg./sq. ft.) were erratic but less so at the higher dosages (Table VIII).

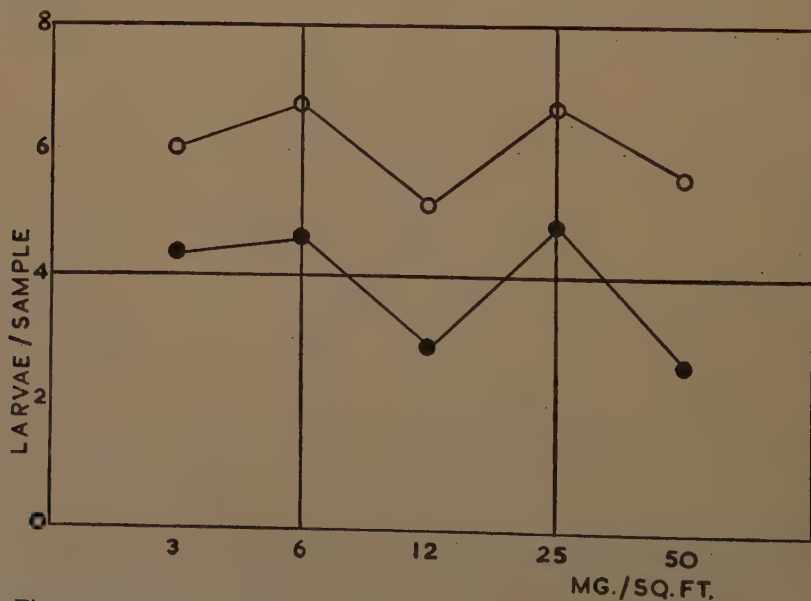


Fig. 4.—Effect of insecticide dosage on larval density. Combined data for malathion, chlordane, dieldrin and aldrin from Soutra site 2. Open and closed circles represent, respectively, the larval densities before and after treatment.

The repeat experiments with DDT and γ BHC at 12 and 50 mg./sq. ft. were disappointing. Neither of the DDT dosages achieved any control, and although the lower γ BHC dosage appeared to be effective, the higher dosage had little larvicidal value. This contrasted with the first trial in which both DDT and γ BHC at 50 mg./sq. ft. caused a useful reduction in larval density. This difference may be related to the weather conditions which prevailed after spraying. There was a period of drought after the treatment of site 2 whilst heavy rain fell after spraying site 1. Hill & Roberts (1947) found that rain increased the larvicidal action of γ BHC miscible oil.

Residual effect.

When the plots were re-sampled after a season of adult activity it was clear that a marked change had occurred in the relative efficiencies of the different larvicides (Table X). Malathion, which had been the most successful insecticide for immediate control, now showed no control except for the wettable powder at 50 mg./sq. ft. Indeed, one of the malathion-treated plots recorded the largest increase in larval density (+207 per cent.) of any of the plots, treated or untreated. The effectiveness of aldrin had decreased by nearly a half from 32 per cent. to 17 per cent. control (Table XII), and none of its reductions were significant. On the other hand, both chlordane and dieldrin had produced larger larval reductions than earlier and in each case three out of the four treatments had achieved statistically significant larval reductions (Table XI). Control by chlordane had improved from 34 per cent. to 48 per cent. while dieldrin had moved from being the least to being the most effective—20 per cent. to 72 per cent. control.

The DDT and γ BHC treatments which had given such poor immediate results now proved to be the most successful residual larvicides. In the first experiment, DDT at 12 and 50 mg./sq. ft. gave, respectively, 80 per cent. and 96 per cent. residual larval control and in the second experiment they achieved 29 and 97 per cent. control, respectively. At the same dosages, γ BHC attained 26 and 86 per cent. control in the first experiment and 71 and 96 per cent. control in the second. This improvement in the effectiveness of γ BHC may be due to the shorter time existing between the application of the insecticide and the period of adult activity. Treatment in the first experiment was almost four months before that in the second. It also appears from these results that the effect of an application of 12 mg. DDT or γ BHC/sq. ft. is likely to vary but 50 mg./sq. ft. produces more consistent results. At the latter dosage, DDT and γ BHC are superior to the same dosage of chlordane and slightly better than dieldrin at 25 mg./sq. ft.

General Discussion.

In the laboratory, larvae of *C. impunctatus* are susceptible to very low concentrations of DDT and γ BHC but, in the field, the difficulty appears to be to make contact between larvae and insecticide. The larvae live in the surface layers of saturated peat, usually below a cover of living *Sphagnum* or *Polypodium*. The problem is how to get the insecticide into this sponge-like material. If this view of the problem is correct, then it follows that water-miscible preparations should be most effective. This is borne out by field experiment when wettable powders and water-miscible concentrates were the most effective larvicides for immediate control. The degree of penetration achieved by these preparations will vary with the detailed topography and drainage of the area. It is not therefore perhaps surprising that the immediate larvicidal effect is very variable. Oil solutions and dusts are unlikely to penetrate the peat and contact larvae and hence their immediate larvicidal effect is slight.

It is quite likely that the assessment of control by larval sampling may lead

to a serious underestimate. If the insecticide remains effective on or near the surface of the soil, then the pupae or emerging adults may become contaminated and killed. This needs to be checked by full-scale field trials.

That the insecticide may remain active for long periods of time is shown by the considerable residual effect achieved by DDT, dieldrin and chlordane. This effect may be achieved either by repelling the ovipositing females or by causing a high mortality among the newly emerged larvae. From the point of view of control, the latter is to be preferred, as repellency might lead to increased breeding taking place in any inadequately treated or overlooked breeding site.

For residual effect, the insecticide must remain at the surface of the soil. This explains the difference between dusts and oil solutions, since the latter will tend to float away on the surface of drainage rain water, while the dusts will be less easily removed. In addition, the insecticide must remain active for a long period. DDT is known to be more persistent than γ BHC which is more volatile, and hence the observed superiority of DDT is to be expected. Similarly, dieldrin is more persistent than the closely related aldrin, whilst malathion like most organic phosphorus insecticides is destroyed by hydrolysis.

The conclusions reached in this paper must be tested by full-scale field experiments in which control is assessed by sampling the adult population. From the point of view of cost, the success of the wettable powders is encouraging since they are the cheapest to prepare of the four formulations tested. Although application of DDT at 200 mg./sq. ft. (= 20 lb./acre) achieved both complete immediate and residual control, such large dosages are costly and not without dangers of toxicity to livestock. This is important as most midge-breeding grounds are used as rough sheep grazing. The applications of DDT at 50 mg./sq. ft. (= 5 lb./acre) to selected breeding sites should be harmless to livestock.

Summary.

Field tests were conducted on Soutra Hill (1,100 ft. above M.S.L.) in the winters of 1953-4 and 1954-5 to find a suitable larvicide for controlling *Culicoides impunctatus* Goetgh. In one trial, four formulations (wetable powder, water-miscible concentrate, oil solution and dust) of DDT and γ BHC were applied to plots (10 x 10 yd.) at dosages of 3, 12, 50 and 200 mg. p,p'-DDT or γ BHC/sq. ft., except for the γ BHC dust which was applied at 3, 6, 12 and 25 mg. γ BHC/sq. ft. In a second trial, the larvicidal properties of aldrin, dieldrin and malathion wettable powders, chlordane water-miscible concentrate and malathion emulsifiable liquid were investigated at three or four of the following dosages—3, 6, 12, 25 and 50 mg./sq. ft. The conclusions to be drawn from these trials were:—

1. DDT was superior to γ BHC at all dosages and in all formulations both in immediate and residual effects.
2. For immediate larval control, DDT and γ BHC wettable powders and DDT water-miscible concentrate were effective but γ BHC water-miscible concentrate was relatively ineffective.
3. Although all the DDT preparations were effective as residual larvicides, the wettable powder was the most successful.
4. For immediate larval control a dosage of 200 mg. p,p'-DDT or γ BHC is required. The effect produced by 50 mg./sq. ft. is variable.
5. For residual larvicidal action a dosage of 50 mg./sq. ft. is required although 12 mg./sq. ft. may sometimes be effective.
6. Both preparations of malathion reduced the initial larval density by just over half but they had no residual effect.
7. Chlordane and aldrin achieved an immediate larval reduction of one third but whereas chlordane had a greater residual effect, aldrin was ineffective.

8. Dieldrin had very little immediate (20 per cent. control) but considerable residual effect (72 per cent. control).
9. Wettable powders are the most successful larvicidal preparations.
10. DDT and γ BHC wettable powders at 50 mg. p.p'DDT or γ BHC/sq. ft. are superior to chlordane at the same dosage and slightly better than dieldrin at 25 mg./sq. ft.

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References.

- CAMERON, A. E. (1948). Scottish blood-sucking midges.—Trans. Highl. Agric. Soc. Scot., **60**, pp. 68–79.
- CAMERON, A. E., DOWNES, J. A., MORISON, G. D. & PEACOCK, A. D. (1946). A survey of Scottish midges.—In Crew, F. A. E. & others, Control of midges, pp. 9–11. Edinburgh, Dep. Hlth. Scot.
- DORSEY, C. K. (1947). Population and control studies of Palau Gnat on Peleliu, Western Caroline Islands.—J. econ. Ent., **40**, pp. 805–814.
- DOVE, W. E., HALL, D. G. & HULL, J. B. (1932). The salt marsh sand fly problem (*Culicoides*).—Ann. ent. Soc. Amer., **25**, pp. 505–528.
- GOLZ, H. H. (1952). Malathion—summary of pharmacology and toxicology.—Med. Dep., Amer. Cyanamid Co.
- GOULDING, R. L., CURRAN, R. F. & LABRECQUE, G. C. (1953). Insecticides for control of salt-marsh sand flies in Florida.—J. econ. Ent., **46**, pp. 37–43.
- HILL, M. A. & ROBERTS, E. W. (1947). An investigation into the effects of "gammexane" on the larvae, pupae and adults of *Culicoides impunctatus* Goetghebuer and on the adults of *Culicoides obsoletus* Meigen.—Ann. trop. Med. Parasit., **41**, pp. 143–163.
- KETTLE, D. S. (1949). An attempt to control *Culicoides impunctatus* Goetghebuer in Scotland by barrier-spraying.—Ann. trop. Med. Parasit., **43**, pp. 284–296.
- KETTLE, D. S. (1951). The spatial distribution of *Culicoides impunctatus* Goet. under woodland and moorland conditions and its flight range through woodland.—Bull. ent. Res., **42**, pp. 239–291.
- KETTLE, D. S. & LAWSON, J. W. H. (1952). The early stages of British biting midges *Culicoides* Latreille (Diptera, Ceratopogonidae) and allied genera.—Bull. ent. Res., **43**, pp. 421–467.
- LABRECQUE, G. C. & GOULDING, R. L. (1954). Tests with granulated BHC and dieldrin for controlling sand fly larvae.—Mosq. News, **14**, pp. 20–22.

IMMATURE NUTFALL OF COCONUTS IN THE BRITISH SOLOMON ISLANDS PROTECTORATE.

By J. S. PHILLIPS *

E.H.N.

(PLATE IX.)

The disorder of coconuts in the British Solomon Islands Protectorate, known as immature nutfall, is caused by the Coreid bug, *Amblypelta cocophaga* China. The disappearance of nutfall in certain areas, during and after the late war, coincided with changes in the ant and bug populations. Visiting investigators have concluded that these changes were due to alterations in the ground vegetation and, consequently, that nutfall could be cured by maintaining certain types of cover-crops and by the use of a "bridging" technique between adjacent palms to facilitate the passage of ants that destroy the bug.

The present paper maintains that the disappearance of nutfall and the changes in the insect populations were due to the long-sustained programme of ground and aerial spraying against mosquitos carried out by the United States occupation forces during and after the war. Experiments prompted by this hypothesis suggest that populations of different species of ants can be differentially affected by applying insecticides, which also will destroy *Amblypelta*.

Review of Pre-war Work.

Over 40 years ago, Froggatt (1911) recorded the presence of immature nutfall in the Solomons, and later Simmonds (1925) suggested that it might be due to many causes, particularly the moth, *Tirathaba rufivena* Wlk., and the weevil, *Diocalandra taitensis* (Guér.).

Tothill (1929), following a short but valuable survey made with R. W. Paine the previous year, concluded that the Pentatomid, *Axiagastus cambelli* Dist., was the main cause of nutfall. He noted the influence of two ant species on the crop: the Red Tree-ant, *Oecophylla smaragdina* (F.), destroyed this Pentatomid, and so the trees on which this ant occurred bore well; the palms bearing the smaller but aggressive ant, *Iridomyrmex myrmecodiae* Emery, were often barren, as it did not destroy the bug. Tothill recommended that the beneficial ant be encouraged and methods be found to introduce nests and increase its distribution. He noted the technique of "bridging" with lianas between palms and he experimented by laying tracks of fallen palm-leaves between the bases of adjacent palms.

In 1929 and 1930, the management of Messrs. Lever's estates experimented with wire-gauze cages, placed round the young spadices of "nutfall" trees to prevent insect attack. When it was found that the caged spadices bore a full crop of healthy, mature nuts, it seemed clear that nutfall was due to the agency of an insect that was too large to pass through the mesh of the cage. This excluded the ants *Pheidole* and *Iridomyrmex*. Nevertheless, during the next few years, nutfall was attributed by fresh investigators to various other causes, including soil conditions, insufficient rainfall, incorrect cultural methods, physiological reasons and the ant *Iridomyrmex*.

The main cause of immature nutfall was proved finally by Lever (1935) to be the Coreid, *Amblypelta cocophaga*. He had first taken this insect in 1932 on coconut spadices, and had subsequently worked out its life-history (Lever, 1933).

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Further investigations (Lever & Phillips, 1936; Phillips, 1940) revealed more details of the inter-relation of nutfall, *Amblypelta* and the associated ants. Usually only a few individuals of *Amblypelta* are found on a palm. The bug injects saliva, containing a toxic substance, into the punctures made by its proboscis. This results in necrosis of the surrounding tissues under the calyx, and nutfall follows. In all cases, a characteristic black, sunken scar develops on the surface of the nut.

The four main species of ants found in plantations in the Solomon Islands were studied in their relations to nutfall. Either *Pheidole megacephala* (F.)* or *Iridomyrmex myrmecodiae* was always found on palms in nutfall areas, while *Oecophylla smaragdina* and occasionally *Anoplolepis longipes* (Jerd.) were the species associated with good-bearing trees. A study of plantation histories on Guadalcanal strongly indicated that *Pheidole* was driving *Oecophylla* from the plantations and this was confirmed by observations in the field (Phillips, 1940), except on Malaita, where *Iridomyrmex* was the prevailing species. Attempts made in 1938 and 1939 to spread the beneficial ants and destroy the harmful ones by various methods all ended in failure.

Attempts at Parasitic Control.

Lever (1935a) bred out a species of *Anastatus* from an egg of *Amblypelta* found on Kolombangara. It was not taken again from *Amblypelta* eggs, but is believed to be *Anastatus axiagasti* Ferrière, the species that commonly attacks the eggs of *Axiagastus*.

In 1936, a fungus parasite was discovered by the writer attacking both nymphal and adult stages of *Amblypelta* taken in Kolombangara and Guadalcanal (Phillips, 1940). This fungus was only in evidence towards the end of the north-west monsoon season (March to May). Attempts in the laboratory to spread this disease to healthy bugs were only partly successful.

Between 1937 and 1940, attempts were made to control *Amblypelta* by parasites sought in Queensland by W. Cottrell-Dormer and in Indonesia by the writer (Phillips, 1941). A number of egg-parasites were imported from both areas. These were bred up and liberated on estates in Malaita and Guadalcanal. Though some of these parasites became established, they failed to exercise any appreciable control of *Amblypelta*.

Small shipments of the Queensland Tachinid, *Pentatomophaga bicincta* de Meij., a parasite of the adult and last nymphal stages of *Amblypelta lutescens* (Dist.), were made by Cottrell-Dormer in 1938 and 1939. Unfortunately, it showed a predilection for the far more numerous *Axiagastus*, in which it failed to develop.

Another Tachinid, *Trichopoda pennipes* (F.), originally from Florida, was brought from Fiji in 1950 and released on a Malaita nutfall estate (O'Connor, 1950b). During 1951 and 1952 over 5,000 bugs (including 2,000 *Amblypelta*) were examined by O'Connor and the writer and no *Trichopoda* larvae were found in any of the Coreids. It must be concluded that this introduction, too, is unlikely to lead to the control of *A. cocophaga*.

Changes in the Ant Population during and after the War.

Pre-war distribution of ant species on Guadalcanal.

The plantations on Guadalcanal belonging to Messrs. Lever's Pacific Plantations Pty. Ltd. (hereafter in this paper referred to as Messrs. Lever's), and in

* In reports in the past, the species of *Pheidole* concerned with nutfall in the Solomons has usually not been named. In the paper quoted (Phillips, 1940), it is recorded as *P. oceanica* Mayr. At that time, there may have been confusion between this and another species, *P. megacephala* (F.), that also occurs in the Solomons and that later work suggests is the more important in the nutfall areas.

particular the Kukum/Lunga/Tenaru group, had been one of the worst nutfall areas in the Solomons in the pre-war decade; the average annual yield dropped from 4.22 to 1.89 cwt. per acre between 1918 and 1934 (Phillips, 1940).

The dominant ant on all these "nutfall" estates had been *P. megacephala*, and observations showed that it had been driving out the other ant species during the pre-war years. The few good-bearing palms in this area carried colonies of *O. smaragdina*, and they bore well because this ant destroyed *A. cocophaga*, whereas *Pheidole* could not do so. A fair inference, and one which the observations of planters and others tended to confirm, is that nutfall had spread because *Pheidole* was driving *Oecophylla* out of these plantations.

Besides these two species, another ant, *Anoplolepis longipes*, had been found in two small areas on these estates. Its influence was beneficial because it, too, destroyed *Amblyopelta*, though not as effectively as did *Oecophylla*. Observations made in 1938 suggested that it might be unable to maintain its position against *Pheidole*.

The small but aggressive ant, *I. myrmecodiae*, which was the dominant ant in nutfall areas on Malaita, was not reported as a significant factor in these Guadalcanal plantations before the war.

Ant-population changes noted after the war.

In 1948, the nutfall position was investigated by Leach and O'Connor, during a two months' visit to the Protectorate, six weeks of it on Messrs. Lever's Kukum/Lunga/Tenaru group of plantations on Guadalcanal. They found the position very different from that of pre-war days. O'Connor (1949) wrote: "There was still a great deal of premature nutfall, but large areas which had previously suffered severely were now in bearing, or coming into bearing again. In these areas *Oecophylla* had re-established itself."

Both these workers made intensive studies of sample areas on the Guadalcanal estates, and the data was recorded by R. Leach (multigraphed report to Unilever on *Amblyopelta* nutfall of coconuts in the Solomon Islands, 1948). We thus have a very useful census of the ant population of palms in these sample plots and the class of crop they bore at that time. It was concluded that in the war years *Oecophylla* had eliminated widespread nutfall here by driving out *Pheidole*.

In May 1950, O'Connor revisited the Solomons and made a short inspection of the Kukum, Lunga and Tenaru plantations. He noted (O'Connor, 1950a): "... almost the whole of these plantations were occupied by *Oecophylla*. The bad nutfall areas where introductions of the beneficial ant had been made were in full bearing, and *Pheidole* was not seen. . . . As most of the palms had produced mature nuts, recovery must have occurred within nine months of our original survey."

While on Malaita, Leach (1948) and O'Connor (1949, 1950a) had noticed the peculiarly intractable problem presented by *Iridomyrmex myrmecodiae*. This ant occurs in thousands on the palms it occupies, and because of its numbers, its habit of constructing earth runways up the trunks and its penchant for building nests in the leaf-bases of the crown, in crevices and cavities in the bole and among the aerial roots at the base, as well as inside the swollen stems of certain epiphytes (Pl. IX, fig. 2), it is extraordinarily difficult to eradicate. Once it is installed, most other ants cannot drive it out. On Malaita estates, it is the dominant ant, and nutfall is worse there than in any other large plantation area in the Protectorate.

Iridomyrmex is also present on Guadalcanal estates, and in the areas from which *Pheidole* has disappeared, it is the only important ant associated with nutfall. Leach (*loc. cit.*) made a rough survey and sketch map of the only *Iridomyrmex* area found on the Kukum/Lunga/Tenaru estates. This area, which

was about 85 acres in extent, was at Tenaru. Two sample plots were made and the ant distribution and crop noted.

Ant distribution in the Kukum/Lunga/Tenaru group in 1952.

In 1952, the writer returned to the Solomons and re-surveyed several of the sample plots laid out by Leach and O'Connor. Some of these had been destroyed and the markings of others had disappeared, so that they were unrecognisable, but enough remained to show the great changes in ant population which had occurred since 1948.

In nearly all cases, the bad nutfall areas of 1948 had become good-bearing areas: but, nevertheless, *Oecophylla* was found to have receded in nearly every sample plot, its place being taken by *Anoplolepis*. This ant had not been mentioned by Leach, and O'Connor alludes to it very briefly, mentioning that it was only rarely encountered. That it was previously present on these estates is evidenced by pre-war reports, but it was then one of the minor species. The only nutfall areas found were some small ones at Kukum and a larger one of

TABLE I.

Comparisons of ant populations, crops and ground cover in 1948 and 1952 on sample plots of coconut palms outside the area occupied by *Iridomyrmex* on the Kukum/Lunga/Tenaru group of plantations, Guadalcanal.

Ant species occupying tree	No. of trees in given plot													
	KB		KC		KD		KEI		LH		LI		LM	
	1948	1952	1948	1952	1948	1952	1948	1952	1948	1952	1948	1952	1948	1952
<i>Pheidole</i>	28	0	89	0	31	0	34	0	7	0	24	0	53	0
<i>Oecophylla</i>	15	2	1	12	43	33	6	29	30	1	23	0	3	0
<i>Anoplolepis</i>	0	36	0	63	0	32	0	3	0	35	0	41	0	53
„ with <i>Oeco.</i> in crown	0	5	0	12	0	5	—	—	0	2	0	1	0	2
Missing trees	—	—	10	13	0	1	—	8	—	—	—	5	—	1
Crop of nuts														
None	25	0	85	0	3	0	31	0	0	0	1	0	15	1
1 or 2 per tree	1	0	3	0	6	3	3	0	2	1	2	0	7	2
1-3 per spadix	3	3	2	1	9	5	0	0	0	4	5	0	10	10
4-6 „ „	9	18	0	19	12	26	1	28	6	24	12	25	19	27
> 6 „ „	5	22	0	67	44	37	5	4	29	9	27	17	5	15
Undergrowth in 1952														
Leguminous creepers	Yes		Yes		Scarce		Yes		Yes		Yes		Yes	
Grasses	Yes		Yes, a little		Yes		Yes		Yes		Yes*		Yes	
Ferns	—		Yes		No		No		No		No		No	
Shrubs	Yes		No		Some		Yes		Yes		No		No	
Many creepers on palms														
	Some		No		No		Many		No		Many		Many	
	Had been allowed to grow waist-high		Had been cleaned just before inspection								*Lalang very plentiful			

In plot LM, south half of plot was waist-high in grass and shrubs, while northern half had thick leguminous crop, which had spread up palm trunks. There was no significant difference in ant population or crop between the two halves. The differences in the numbers of trees on plots KD and LH in 1948 and 1952 are probably due to destruction of some trees in the interval.

some 50 acres on Tenaru estate, all colonised by *Iridomyrmex*. These will be commented on later in this paper. Even in these areas, the intensity of nutfall was nothing like so heavy as in pre-war days.

Table I gives particulars of the sample plots outside the *Iridomyrmex* area. The re-survey of these plots showed that the recovery from nutfall, noted in 1948, had continued, but that pronounced changes had occurred in the ant population.

The whole of the *Iridomyrmex* area sketched in 1948 was re-surveyed by the writer in 1952, the altered boundaries of the different ant species present being marked by painting the palm-trunks with coloured rings. The 1948 and 1952 limits of these areas are given in fig. 1; they show that *Iridomyrmex* had been driven back by *Anoplolepis* and that the area occupied by the former ant had

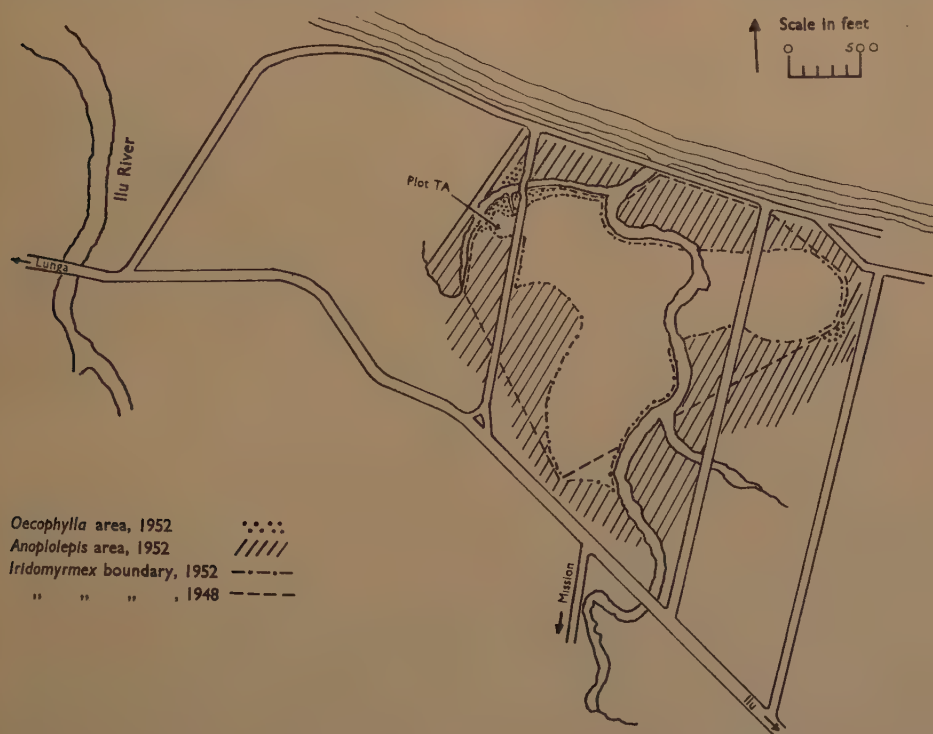


Fig. 1.—Sketch map of *Iridomyrmex* area at Tenaru, showing areas occupied by *Oecophylla* and *Anoplolepis* in 1952, and boundaries of *Iridomyrmex* area in 1948 and 1952.

been reduced from 85 to 50 acres in four years. The regression was irregular, for *Anoplolepis* had made deep salients in some parts and little headway in others, while in a small area to the south, adjoining the creek, *Iridomyrmex* appears to have made a slight advance; this may have been made earlier at the expense of *Oecophylla* or *Pheidole*, before *Anoplolepis* invaded the area. Two small patches of *Oecophylla* still persisted on the borders of the area occupied by *Iridomyrmex*, but all the rest of the area was bounded by *Anoplolepis*-occupied palms.

This advance of *Anoplolepis* into the *Iridomyrmex* area seemed a very promising development, for, judging from the good crops in the regions at Kukum and Lunga now occupied by *Anoplolepis*, this ant appears to be capable of controlling *Amblyopelta* and, therefore, nutfall, whereas *Iridomyrmex* cannot do so.

To form some estimate of the comparative effect of the ant species present here on the yield, samples of twenty trees were taken in each of the following three areas:—

- (a) an *Oecophylla* patch adjoining the *Iridomyrmex* area,
- (b) an *Anoplolepis* area nearby, which had been *Iridomyrmex* territory in 1948,
- (c) an *Iridomyrmex* area close to (a) and (b).

Results were as follows:—

Area	Species of ant	No. of trees with no nuts	1 or 2 nuts per tree	1-3 nuts per spadix	4-6 nuts per spadix	> 6 nuts per spadix
a	<i>Oecophylla</i>	0	0	2	7	11
b	<i>Anoplolepis</i>	0	2	5	9	4
c	<i>Iridomyrmex</i>	1	4	7	5	3

These figures suggested that the supersession of *Iridomyrmex* by *Anoplolepis* would make for an improvement of the crop, but that *Oecophylla*-occupied trees would bear better still.

In re-examining in 1952 the smaller of the two sample plots that Leach had made in this area in 1948, the writer found that *Anoplolepis* (not present in 1948) had invaded the plot and not only driven out *Oecophylla* but also expelled *Iridomyrmex* from about two-thirds of the area it had occupied. Particulars of the changes in this plot (TN) are given below: the larger plot had also been invaded by *Anoplolepis* with similar results.

Mimosa pudica predominated in the undergrowth, together with other leguminous cover crops, grass, a few shrubs and some fern, but there were no creepers on the palms.

The question arises as to why *Anoplolepis* has suddenly invaded extensive areas of Guadalcanal recently and become the dominant ant there. Before the

TABLE II.

Comparison of ant distributions in 1948 and 1952 on plot (TN) previously dominated by *Iridomyrmex*.

Species of ant	No. of trees colonised	
	1948	1952
<i>Pheidole</i>	0	0
<i>Oecophylla</i>	25	2
<i>Iridomyrmex</i>	111	41
<i>Anoplolepis</i>	0	86
„ with <i>Oecophylla</i> in crown	0	2
„ with <i>Oecophylla</i> on trunk	0	2
Trees broken since 1948	—	3

In 1952, of the 23 trees formerly occupied by *Oecophylla*, one tree was found to be colonised by *Iridomyrmex* and the remaining 22 by *Anoplolepis*.

war, it was established as a minor species in many parts of the Protectorate. In 1936, a small invasion of this ant occurred on a Kolombangara estate, and the writer noted then that it destroyed *Amblyopelta* and might be a good control for that bug, if it could be established in other nutfall areas. Later, colonies of this ant were found at Kukum and attempts were made to spread it by feeding it and putting poison-bait inside the adjoining *Pheidole* area: a similar test was made at Tenaru, where other *Anoplolepis* colonies had been located. These methods did not succeed: in fact, during the tests, *Pheidole* was found to be spreading slowly into the *Anoplolepis* area.

The 1948 investigators did not find *Anoplolepis* at all in their sample plots; nor does O'Connor mention it occurring in 1950. Yet by 1952 it had become the dominant ant throughout these Guadalcanal plantations. The invasion must have been a very rapid one.

What was the new factor that operated from 1950 onwards? The only one apparent is a negative one, namely, the disappearance of the previously dominant species, *Pheidole*. Is it possible that with the disappearance of this ant, *Anoplolepis* found its successor, *Oecophylla*, a much less formidable adversary and so was able to spread unchecked?

Anoplolepis has also begun to replace *Pheidole* in other areas from which this ant has disappeared, for example, parts of plantations in the Russell Islands. This area has one factor in common with the Kukum/Lunga/Tenaru plantation-complex, and this is that both places were important bases for United States forces for a prolonged period during the war.

Ant distribution in other plantations.

The writer spent some months visiting coconut plantations in other parts of the Solomons and found no area which showed the dramatic recovery from nutfall displayed by the Lunga/Kukum/Tenaru group of estates. On the contrary, the yield had decreased almost everywhere.

In general, *Pheidole* was the dominant ant in the nutfall areas (except on Malaita plantations, where *Iridomyrmex* was dominant) and indeed it had greatly extended its pre-war area of occupation.

A striking instance is Ruavatu estate on Guadalcanal, some twenty miles from the Lunga group. Here, in 1936, *Oecophylla* was the dominant ant and no signs of nutfall were noted till 1937.* Surveys in 1953 showed that *Pheidole* then occupied most of the plantation. The yield of copra had fallen from 8.04 cwt. per acre in 1938 to 1.4 cwt. in 1952. In contrast, at Lunga the yield had risen from 0.8 to 4.7 cwt. in the same period and *Pheidole*, the dominant ant before the war, had disappeared from this estate.

In the Russell Islands, where there is no *Amblyopelta* and consequently no immature nutfall of this type, *Pheidole* has also been ousted, by *Oecophylla* and *Anoplolepis*.

Cover-crop Theory of Ant-population Change and Nutfall Recovery.

The cover-crop theory.

The 1948 investigators had found that *Oecophylla* used cover-crop creepers such as *Centrosema pubescens* and *Pueraria javanica*, as well as fallen palm-fronds, for its pathways, and they noted that where these were established, *Oecophylla* was the dominant ant, but where the plantation floor was covered with grasses, or with *Mimosa pudica* or *Triumfetta bartrami*, *Pheidole* was the prevailing species. They also formed the opinion that when the plantation ground-cover was kept close-cropped by cattle, this condition favoured *Pheidole*.

Leach (*loc. cit.*) concluded that "the change in the ecological conditions

* From unpublished reports to Messrs. Lever's by the writer.

within the plantations had altered the situation completely since the War. Vines, growing up the base of the palms, had inadvertently allowed *Oecophylla* to get on the trunks of the palms without having to encounter the *Pheidole* strongholds at the base of the palm. In this way *Oecophylla* had become re-established in areas from which it had previously been evicted."

O'Connor (1950a), in support of this theory, made three experiments in which *Oecophylla* nests were introduced into the crowns or on to the trunks of *Pheidole*-occupied palms in nutfall areas. Runways were provided from trunk to ground by heaping fallen coconut-fronds against the base of the palm, thus by-passing the nests of *Pheidole* among the palm-roots, and these palms were also connected with their neighbours by lines of fallen fronds laid on top of the undergrowth.

When these palms were re-examined some six weeks later, it was found that the *Oecophylla* colonies had managed to survive and that, moreover, to a large extent they had protected the youngest spadices (which had opened after *Oecophylla* had been placed in the crowns) from attack by *Amblyopelta*. It may be noted, however, that none of these palms, nor any of the others to which *Oecophylla* had been introduced, bore colonies of this ant when re-examined by the writer in 1952: they were instead occupied by *Anoplolepis*.

The evidence opposed to the cover-crop theory.

It is perfectly true that the recovery of these Guadalcanal estates was due to the re-occupation by *Oecophylla* of many of the palms held by *Pheidole* before the war, but that the altered ecological conditions in the plantation undergrowth caused this change of population is an assumption that is contradicted by examination of subsequent conditions here and in other estates in the Protectorate.

The evidence opposed to the cover-crop theory may be summed up as follows:

(i) *Evidence from pre-war conditions.*

Leach (*loc. cit.*) stated that, before the war, the plantations were grazed by cattle and kept spotlessly clean, "like a lawn". This was a fair description of some estates in the Russell Islands, but not of the plantations that were investigated on Guadalcanal. The writer spent many strenuous days in 1935-39 struggling through the dense and often thorny undergrowth of these plantations: it was usually knee-high and often higher. The character of the vegetation varied: some of it contained the types believed by Leach to favour the presence of *Pheidole*, in other parts there were areas of the cover-creepers he associated with the dominance of *Oecophylla*. But irrespective of the vegetation, the only good-bearing areas were those close to the sea. Nutfall had come in from the bush and was gradually advancing, as indicated by a study of the yield history of these blocks (Phillips, 1940).

Leach maintained that because of neglect due to war and post-war conditions, the "lawn-like" undergrowth that he considered favourable to *Pheidole* became covered in some areas with certain types of creepers favouring the establishment of *Oecophylla* and that the consequent recovery from nutfall in such areas was really due to the neglect of normal weeding and clearing operations and the consequent change in the ecology of the plantations.

Adjoining Tenaru, however, is Ilu estate. This was a bad nutfall area, in which cleaning had stopped several years before the war, so that it had plenty of luxuriant undergrowth in the late thirties. The writer saw it several times between 1935 and 1939, when its manager stated it was not worth the trouble of working, yet the neglect of normal weeding and clearing operations then did not bring it back into bearing. Nevertheless, after the war this estate did come back into bearing, and bore well. In 1948, sample plots made here showed that about

90 per cent. of the palms then carried colonies of *Oecophylla* in the good-bearing areas and about 20 per cent. in the remaining heavy-nutfall area. In 1952, this latter area had also recovered and nearly all the palms there carried colonies of *Anoplolepis*.

(ii) *Evidence from areas not investigated in 1948.*

Owing to lack of time, the only nutfall area studied by the 1948 investigators was the Kukum/Lunga/Tenaru group of plantations on Guadalcanal, except for a few days spent on a Malaita estate, where *Iridomyrmex* was the dominant ant. This was most unfortunate, because the position of these estates, adjoining United States Army Headquarters during the war, had brought them special treatment not accorded to any other extensive nutfall area. This factor is discussed later.

The same vegetational changes that occurred on these Guadalcanal estates during the war years took place in every other plantation in the Solomon Islands, but no concomitant recovery from nutfall occurred elsewhere. In fact, nutfall areas spread and their intensity increased. Had the 1948 investigators been able to examine nutfall areas elsewhere, they must have formed very different conclusions.

(iii) *Evidence from the Russell Islands.*

Had time permitted a more detailed exploration in 1948 of the area then examined, this would have shown that the supposed association of ant species with definite types of plantation undergrowth was probably as honoured in the breach as in the observance. Palms, with creeping cover crops of the *Pueraria* type round their trunks (Pl. IX, fig. 1), are just as likely to harbour *Pheidole* as *Oecophylla*, and even "lawn-like" undergrowth is not necessarily favourable to *Pheidole*. At Faielau, in the Russell Islands, such conditions had been found and a sample plot marked out having a great preponderance of *Pheidole*, with only a few trees tenanted by *Oecophylla*, in what was, on the whole, *Oecophylla* territory: it was suggested that these estates would provide excellent conditions for watching the encroachment of *Pheidole* into *Oecophylla* territory (Leach, *loc. cit.*).

Since that time, the same conditions have continued; the estate has been kept heavily grazed by cattle and it is probably the most "lawn-like" of Messrs. Lever's plantations; fallen fronds are still burned at intervals and there are no cover-crop vines. Yet *Oecophylla* has advanced and now occupies over three-quarters of the palms. Mr. A. H. Green made a census of this plot in August 1952, and the figures below are given here with his kind permission.

Species of ant	Percentage of palms occupied	
	1948	1952
<i>Pheidole</i>	84.3	22.0
<i>Oecophylla</i>	15.1	78.0

O'Connor (1950a) describes the leaf-nests made in the palm-crowns by *Oecophylla* and the nests in epiphytes and spathes in which *Iridomyrmex* rears its broods, and contrasts these with the nests of *Pheidole*, made among the aerial roots just under the apron and also in various places on and under the plantation floor: the aim of Leach and O'Connor's "bridging" technique between ground and trunk was to bypass these nests in safety, so that *Oecophylla* had free access to the palm-crowns.

The normal habit of *Pheidole*, however, is to make subsidiary nests in the leaf-bases of palm-crowns, as was discovered both before and after the war in other nutfall areas. The writer recorded an observation at Kukum in 1938 that *Pheidole* colonies are established not only at the foot of the palms—where they could be dealt with effectively—but also in the crowns, in leaf axils and in old

spadices, and this was confirmed at Ruavatu in 1953, where 10 *Pheidole*-occupied palms were examined: all of these had subsidiary nests in the crowns.

If the *Pheidole* population in the area examined by the investigators in 1948 had been drastically reduced by the factor examined in the next part of this paper, it is quite possible that the palms they examined had no subsidiary crown-nests: for, as the writer has found in Hawaii, this ant makes an increasing network of subsidiary nests after it has built up the population of the main nest. It may well be that it was a lack of subsidiary crown-nests that accounted for the ease with which Leach and O'Connor were able to establish *Oecophylla* on *Pheidole*-held trees with their leaf-bridge technique. I am indebted to Mr. A. H. Green for this suggestion.

Spray Hypothesis of Ant-population Change and Nutfall Recovery.

Anti-malarial spraying programme of the United States forces.

If we reject the cover-crop theory of nutfall recovery—as I think we must—then the most likely explanation to cover all the facts is that the recovery was due to the effects of the spraying programme of the United States forces. This was carried out by their occupation units during and for some time after the war. It has not been possible to obtain precise details of this programme, but it seems certain that a regular weekly aerial spraying was carried out against malaria-carrying mosquitos between 1952 and 1956 and at irregular intervals for some time afterwards. In addition, knapsack sprayers were used against all possible mosquito breeding places in the plantations. In the aerial spraying, two quarts per acre were applied of the following formulation: DDT 10 per cent., Cyclohexanone 5 per cent., diesel oil and engine oil in equal parts 85 per cent.*

The area sprayed overlapped the Kukum/Tenaru/Lunga plantation-complex, for Honiara, which was the headquarters of the United States Army in this area, adjoins Kukum, and Lunga was the site of the main airfield. Ruavatu estate is outside the area where systematic spraying occurred. The Russell Islands were a United States naval base during the war and here, too, a spraying programme of a lesser duration and extent was carried out. It is in these two areas that the striking changes in ant population occurred.

Direct effect of insecticidal sprays on Amblyopelta.

Our tests at Ruavatu (p. 593) indicate that DDT has a lethal effect on *Amblyopelta*, both by contact and residually. The dosage used by the United States forces was intended for use against mosquitos, but was sufficiently heavy to kill both ants and bugs by contact, and the cumulative effect of weekly sprayings over a period of years must have left highly lethal dosages on the foliage of the sprayed areas.

In aerial spraying experiments in Zanzibar against *Pseudotheraptus wayi* Brown, a coconut bug closely allied to *Amblyopelta*, a very high kill was obtained with a single application, using only half as much insecticide as was used on Guadalcanal, namely, one quart per acre of a 10 per cent. solution of DDT in a 1:1 mixture of kerosene and dieseline. Six weeks after spraying, there was a healthy crop of young nuts on all the palms (F. L. Vanderplank, personal communication).

The almost total disappearance of *Amblyopelta* from the sprayed areas near Honiara and its presence in normal numbers in plantations elsewhere in the Solomon Islands that were not covered by the United States spraying programme, offers very strong confirmation of the theory that it was eliminated by the spraying.

* I am indebted to Captain O. L. Burton, Director of the Preventive Medicine Division of the U.S. Navy for this information (letter of 2nd November 1953).

Differential effects of spraying on the ant species.

The reason why *Oecophylla* was able to occupy the areas held in pre-war days by *Pheidole* in this sprayed group of plantations is believed to be that the insecticide used had a differential effect on the two ants: a very lethal one on *Pheidole* and only a very slight one on *Oecophylla*. Thus, the colonies of *Pheidole* were subjected to a process of continuous attrition, while those of *Oecophylla* were practically unaffected and thus able to extend their hold on these plantations.

This theory was first indicated by the tests at Kukum and Tenaru (described later) and it is supported by the experiments at Ruavatu (see p. 588). It is further confirmed by the tests made in Zanzibar by Vanderplank, who found that after hand-spraying an area of 1,000 palms every three months with a DDT formulation, the percentage of palms with *Oecophylla* nesting in them increased from 6 to 20 per cent. in nine months. The other ants here were species of *Pheidole*, *Anoplolepis* and *Crematogaster*.

Experimental Attempts to confirm the Spray Hypothesis.

In order to test the spray hypothesis, a number of small-scale experiments were carried out, in the first instance against *Iridomyrmex*, using a knapsack-sprayer which was the only type available. With this, only the base of the palm and the bottom eight feet of the trunk could be reached: the upper trunk and the crown, and thus the ants living in subsidiary nests in the leaf-bases and in the earth-covered runways, could not be sprayed. Nevertheless, it was argued that, using a residual-type insecticide, many of these ants might be killed, if and when they moved down towards the base of the tree over the sprayed portion, as this species is a slow mover and so might remain long enough in contact with the insecticide to absorb a fatal dose. Furthermore, they might carry some of the insecticide back to the nest and then be cleaned and licked by other ants, which might absorb it in their turn and also be affected. The whole colony might thus be sufficiently weakened to be quickly overrun by invasion from neighbouring *Anoplolepis* colonies.

Two insecticides were tested, (a) 1:500 solution of "Octaklor" (chlordane) emulsion in water, and (b) 1:100 emulsion of "Pespruf 20 mayonnaise" with water; the latter is a DDT preparation. In all cases, about 1,500 cc. of spray was used per tree, the amount varying slightly according to the diameter of the trunk and the various irregularities and crevices therein.

(a) Pilot tests at Tenaru.

Two sites were selected on the border of the *Iridomyrmex* area. On the first of these a group of six *Iridomyrmex*-held palms was sprayed with chlordane on 29th December 1952, and a day later two groups of eight palms each were treated similarly with DDT. Control groups were chosen in each case.

Nine days after spraying, five of the first group of palms bore *Anoplolepis* colonies on their boles, the sixth had no ants of any kind on its trunk. Of the control trees, five still carried *Iridomyrmex*, the sixth had been invaded by *Anoplolepis*.

However, on sending a boy up one of the sprayed trees, he found only *Iridomyrmex* colonies in the crown, though *Anoplolepis* had occupied the bole. This raised the query: would the latter ant be able to extend its occupation to the unsprayed crown or would the *Iridomyrmex* colonies there be able to recover and drive back the invaders? These six palms were re-examined a month later. Three of the trunks were still in possession of *Anoplolepis*, two were in joint possession of both ants with the species on opposite sides of the bole and the remaining tree had been reconquered by *Iridomyrmex*. This suggested that spraying the tree up to eight feet from the ground is insufficient to turn the balance permanently in favour of the invading ant.

The remaining groups of trees, sprayed with DDT, gave a somewhat similar result. Here about half the trees carried colonies of invaders ten days after spraying, and a month later a few boles, which had borne these colonies, were reoccupied by *Iridomyrmex*. The results suggested that initially chlordane was more effective than DDT against *Iridomyrmex* but that the residual effect of DDT was more lasting.

(b) *Spray plot at Tenaru.*

As the preliminary results of the pilot tests had been encouraging, it was decided to try a similar experiment on a somewhat larger scale, to see whether it was possible by this means to speed the reduction of the *Iridomyrmex* area and, therefore, the nutfall area. No really large-scale tests were possible with the equipment and personnel available.

Accordingly, an area of about one acre was chosen on the border of the *Iridomyrmex* area at Tenaru (plot TA, fig. 1). It was brushed* and on 23rd and 26th January 1953 it was sprayed with the same formulation of chlordane as used in the pilot test. Only the 46 *Iridomyrmex*-occupied trees were sprayed, including two with some *Anoplolepis* also on the bole. The *Oecophylla*-held trees were left unsprayed. The cost of labour (two boys with knapsack sprayers) and material was about £A.1. The site chosen had colonies of all three species of ants round its periphery. All the trees were marked and numbered and a record of their yield was taken for comparison with the yield later on. This record is as follows:—

Crop of nuts	No. of trees occupied by	
	<i>Iridomyrmex</i> (including a few <i>Anop.</i> trees with <i>Irido.</i> in crown)	<i>Oecophylla</i>
None	3	0
1 or 2 nuts per tree	5	0
1-3 nuts per spadix	34	1
4-6 nuts per spadix	5	4
>6 nuts per spadix	1	13

The data given in Table III show the surprisingly good results obtained at first by this measure, which enabled *Anoplolepis* to invade and occupy two-thirds of the plot in two months. After four months, three-quarters of the plot had been occupied, but later there was an *Iridomyrmex* recovery, almost certainly due to counter-attacks from the unsprayed crowns. This indicates that the spraying of the base and lower trunk may be insufficient to oust *Iridomyrmex* and suggests that the upper trunk and crown should also be sprayed: this can only be done with a power sprayer, and would have the additional advantage of killing any *Amblyopelta* that might be in the crowns.

As a control for this plot, another one of similar size, some 50 yards away, was used. Throughout the course of the test, there was no change in the population of the control plot.

A parallel experiment was made at Mamara, an estate eight miles west of Honiara, where *Iridomyrmex* also occupied all the nutfall areas; here the

* "Brushing" means cutting the undergrowth with a bush-knife.

border-ant was *Oecophylla*, not *Anoplolepis*. The results were disappointing, as this ant only made a small, temporary advance of three palms, which *Iridomyrmex* recovered after two months. *Oecophylla* seems unable to make any headway against *Iridomyrmex* when only the base and lower trunk of the palms are sprayed. No doubt this is because *Oecophylla* always nests in the crown, which was not

TABLE III.

Results of spraying *Iridomyrmex*-held palms at Tenaru (plot TA).

Palm-trunks held by	Months after spraying			
	1	2	3½	5
<i>Anoplolepis</i>	15	30	33	28
<i>Oecophylla</i>	3	4	3	1
<i>Iridomyrmex</i>	16	10	8	16
? <i>Paratrechina</i>	2	2	2	1
No ants	10	0	0	0

sprayed and was full of unaffected *Iridomyrmex*. The main nests of *Anoplolepis*, however, are usually at the base of the palms, so that they are able to establish themselves unmolested.

(c) *Pilot test at Kukum.*

The tests reported above (a and b) had all been made against *Iridomyrmex*-held palms with the aim of a rapid reduction of the nutfall area.

The nutfall recovery associated with the war, however, had occurred in an area subjected to regular and indiscriminate spraying over a period of years, and *Pheidole*, dominant here before the war, had first receded and then disappeared, while the beneficial ant *Oecophylla* had replaced it, and become dominant in 1948-50. As this change had not occurred in any other nutfall area, it seemed likely that it was a result of wartime anti-malarial spraying and that, as suggested above, the insecticide used had had a differential effect on the ant species—a very severe one on *Pheidole* and an almost negligible one on *Oecophylla*.

As *Pheidole* had disappeared from the Kukum/Lunga/Tenaru area, it was impossible to include this species in any local test, although an opportunity to test it occurred later elsewhere (see below, (d)). Meanwhile, as it was thought interesting to find out the comparative effect of insecticides on the species that were still present, a small plot was selected at Kukum, where *Oecophylla*, *Anoplolepis* and *Iridomyrmex* were all present.

A plot of 27 trees was chosen for this test, of which *Iridomyrmex*, *Oecophylla* and *Anoplolepis* each occupied nine trees. All the trees were numbered and ringed with different coloured paints, according to the ant species they bore. Nine trees (three bearing each species) were sprayed with chlordane in the same way as in the earlier tests; another lot of nine were similarly treated with DDT and the remaining nine were left untreated as controls. On the trees sprayed with chlordane, the ants were killed very quickly, the effects of DDT seemed much slower but appeared to be somewhat more lasting.

The results of the test are given in Table IV. They seem to indicate that when the bases and lower trunks of palms are sprayed in an area held by a mixed

population of these three ant species, *Oecophylla* is the least affected and makes initial territorial gains, whereas *Iridomyrmex* is more seriously affected than the other two species and loses ground to them. After about two months, however, when the effects of this type of limited spraying have worn off, *Iridomyrmex* appears to recover most of its lost ground and *Oecophylla* loses its previous gains. *Anoplolepis* is slightly affected at first, but later recovers ground more quickly than does *Iridomyrmex*.

TABLE IV.

Effect on mixed ant populations of spraying the palm-base.

Species of ant	No. of palm-trunks held at various intervals after spraying			
	1 week	2 weeks	2 months	3 months
<i>Iridomyrmex</i>	2*	2*	4½	4½
<i>Oecophylla</i>	5	10	6	4
<i>Anoplolepis</i>	2	4	5½	9½
No ants	9	2	2	0

Notes: * A few individuals only.

"½" signifies that the bole was shared by colonies of two different species.

There were no changes in the nine control palms throughout the course of the experiment.

(d) *Spray test with Pheidole at Ruavatu.*

Ruavatu estate is one of Messrs. Lever's plantations on Guadalcanal outside the area subjected to the United States forces' spraying programme. Its yield and ant population offer an interesting contrast to those at Lunga, a typical estate inside the spraying zone.

	Dominant ant (1936-39)	Dominant ant (post-war)
Ruavatu	<i>Oecophylla</i>	<i>Pheidole</i>
Lunga	<i>Pheidole</i>	<i>Oecophylla</i> (1948-50)

Below are figures of average yield in cwt. per acre on these estates in certain years:—

	1929	1936	1937	1938	1939	1940	1952
Ruavatu	—	—	—	8.04	5.21	4.75	1.4
Lunga	7.1	1.5	0.8	0.8	—	—	4.7

When the writer inspected Ruavatu in 1936, the dominant ant there was *Oecophylla* and there were no signs of nutfall; but the following year nutfall was noted near the Mission boundary, and it spread rapidly throughout the plantation, as the above figures show. In 1953, *Pheidole* occupied more than two-thirds of the estate.

During the pre-war period, Lunga suffered from severe nutfall in all its blocks, except along the coastal strip. *Pheidole* was the dominant ant there, and

Oecophylla was found only in the coastal areas and in a few isolated patches inland. The records show (Phillips, 1940) that in 1929, the average yield at Lunga was 7.1 cwt. per acre and that it diminished year by year in the pre-war decade; so the low yield in the thirties was abnormal and due entirely to spreading nutfall.

Because of the dominance of *Pheidole* at Ruavatu and the fact that this estate was outside the area that had been covered by the wartime spraying, it provided an ideal opportunity to test the spraying hypothesis of nutfall recovery.

The tests made here were planned and carried out in conjunction with Mr. A. H. Green of Messrs. Lever's Pacific Plantations, and he is continuing them. The experiments were on a somewhat larger scale than those described earlier in this paper. "Pespruf 20" DDT emulsion concentrate, diluted 1:100 with water was used throughout, as we had run out of chlordane. As before, the lower trunks and bases of the palms were cleaned before spraying. The ant distribution and site of the sample plots on Ruavatu estate are shown in fig. 2.

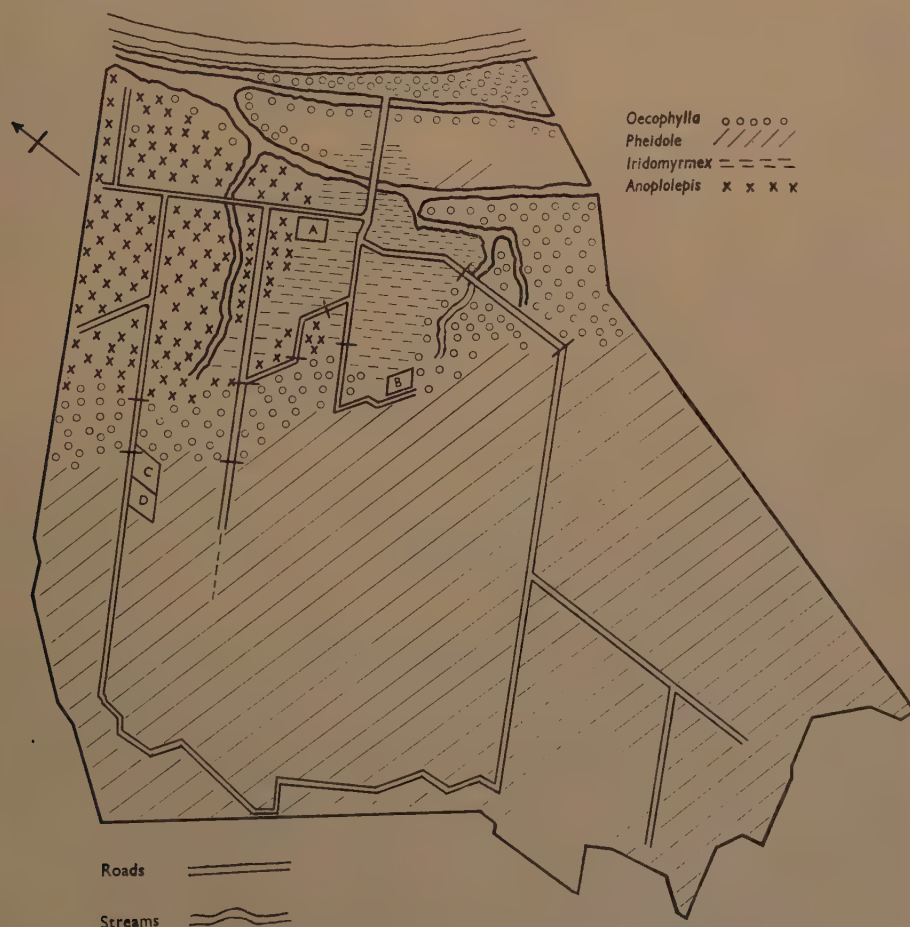


Fig. 2.—Plan of Ruavatu estate, showing approximate distribution of four species of ants, June 1953. Approximate scale, 3 inches = 1 mile. The plan is accurate only immediately adjacent to the roads. The bars across the roads indicate a change in the species of ant bordering the roads. The sites of spray trials in June 1953 are labelled A, B, C and D.

Plot B.—This sample plot was chosen at the junction of *Pheidole*, *Iridomyrmex* and *Oecophylla* areas and contained 105 trees, which were marked and numbered and their crops and ant populations recorded. The plot was sprayed on 9th June 1953, alternate trees being left unsprayed as controls.

The plot was inspected five weeks later. The sprayed trees showed a marked reduction in the number occupied by *Pheidole*, a lesser but still notable reduction of those tenanted by *Iridomyrmex* and an increase of those occupied by *Oecophylla*. The unsprayed (control) trees also showed some lesser changes, perhaps denoting disturbances due to the spraying of their neighbours or cleaning operations round the palm-bases. Details were as follows:—

Species of ant	No. of palms occupied by given species of ants			
	Sprayed		Unsprayed	
	9.vi.	17.vii.	9.vi.	17.vii.
<i>Oecophylla</i>	12	16	13	16
<i>Pheidole</i>	12	3	8	6
<i>Oecophylla</i> + <i>Pheidole</i> ..	1	0	3	0
<i>Iridomyrmex</i>	20	12	18	19
<i>Oecophylla</i> + <i>Iridomyrmex</i>	0	0	1	0
<i>Pheidole</i> + <i>Iridomyrmex</i> ..	0	0	0	2
Other spp.	0	0	1	1
No ants	0	14	0	0
Total	45	45	44	44

Note: Where two ants are given in the species column, it shows that the palms in question were jointly occupied by colonies of these two species.

Plot C.—This plot consisted of 100 palms (less 6 dead or missing ones) on the boundary between *Oecophylla* and *Pheidole* areas. The plot was in the *Oecophylla*-dominated part of the boundary area. The trees were marked and numbered and their crops recorded, as before, and on 11th June 1953 alternate trees in the plot were sprayed.

The plot was inspected about five weeks later. The results (see Table below) showed a complete wipe-out of *Pheidole* and an increase in the number of palms tenanted by *Oecophylla*. The unsprayed (control) palms showed very slight changes, and these were no doubt due to cleaning and spraying neighbouring trees. Details were as follows:—

Species of ant	No. of palms occupied by given species of ants			
	Sprayed		Unsprayed	
	11.vi.	14.vii.	11.vi.	14.vii.
<i>Oecophylla</i>	17	20	23	27
<i>Pheidole</i>	5	0	6	5
<i>Oecophylla</i> + <i>Pheidole</i> ..	4	0	1	0
Other spp.	1	1	0	0
No ants	20	26	17	15
Total	47	47	47	47

Plot D.—This also consisted of 100 palms (less 6 dead or missing ones), all inside the *Pheidole* area and adjoining plot C, in fact a prolongation of that plot into the *Pheidole* area. Here, too, the trees were marked and numbered and

their crops recorded, and the usual cleaning was done. On 12th June 1953, alternate trees in the plot were sprayed and it was inspected five weeks later.

The results again show a very striking reduction in *Pheidole*-occupied trees; but as there were no *Oecophylla* colonies nearby to move in, they remained tenantless (except in one case), at least as far as the trunks and bases were concerned. As the crowns remained unsprayed, it seems likely that the lower parts of these palms will be re-occupied by *Pheidole* eventually from their crown-nests, as soon as the insecticide ceases to be lethal. The unsprayed (control) palms also showed some losses of colonies, due no doubt to the causes mentioned previously. Details are as follows:—

Species of ant	No. of palms occupied by given species of ants			
	Sprayed		Unsprayed	
	12.vi.	18.vii.	12.vi.	18.vii.
<i>Oecophylla</i>	0	0	0	0
<i>Pheidole</i>	37	14	35	29
<i>Oecophylla</i> + <i>Pheidole</i> ..	0	1	0	0
Other ants	5	2	5	4
No ants	6	31	6	13
Total	48	48	46	46

The preliminary results of these tests show very clear differential effects on the ant species present and give strong indications of what must have happened in the areas subjected to the wartime spraying programme.

The writer left the Protectorate in August 1953 and was unable to make further inspections of these plots, but his colleague Mr. Green has very kindly agreed to do so from time to time.

Possible Use of Insecticides to control *Amblyopelta*.

The experiments described in the foregoing section seemed to offer strong support for the hypothesis that insecticidal sprays could be used to control *Amblyopelta* either directly or indirectly, by altering the pattern of the ant population. While they were being conducted, the writer received further information from Zanzibar, to the effect that as a result of hand-spraying of coconut palms in 1952 with a DDT formulation every three months in order to eradicate *Pseudotheraptus wayi*, the proportion of palms with *Oecophylla* nesting in them increased markedly. The ant population included species of *Pheidole* and *Anoplolepis* and was thus similar to that of the Solomon Islands plantations. The formulation used was highly lethal to *Pheidole* and *Anoplolepis* but had little effect on *Oecophylla* (F. L. Vanderplank, personal communication). Further information from the same source in 1953 confirmed that what appeared to be complete eradication of *P. wayi* could be obtained by application of suitable formulations of DDT.

Tests with atomised sprays.

By February 1953, it had become clear that the limited effects obtainable with a knapsack sprayer would be insufficient to enable the beneficial ants to oust the harmful species quickly, and that a type of sprayer was needed that would cover the crowns as well as the lower parts of the palms. Using such an apparatus, a fairly rapid change of ant distribution in favour of the beneficial species might be expected. In the case of *Anoplolepis*, the plantation areas it occupied would be likely to remain in its possession, for recent surveys had shown that, without

any assistance, it was driving all the other species out of the plantations, though only very slowly in the case of *Iridomyrmex*.

Apart from any effects on the ants, crown spraying should have a direct effect on nutfall by killing *Amblyopelta*, and the replacement of ineffective ant species by others that would control this bug should ensure that the areas thus occupied would not become nutfall areas again.

Enquiries showed that it was not possible to procure an apparatus capable of projecting a spray-stream as high as the palm-crowns (60 ft. above the ground) that would not be far too unwieldy and uneconomical for our purpose. The only appliance practicable would be of the atomiser type. This would be able to blanket the crowns, be light enough to use in a coconut plantation and would need only a fraction of the liquid required to cover the same area with a spray of the conventional type. It would thus be economical.

Two questions then arose. Would an atomiser spray be effective against *Iridomyrmex*? This ant makes earth-covered runways up the trunks of palms, and though the liquid stream from a knapsack sprayer is strong enough to dissolve these, the gentle mist from an atomiser might not do so. Would the atomiser mist kill *Amblyopelta* on contact, and would the thin film of residue it left be lethal? The following tests were accordingly carried out, using atomised sprays:—

(i) Tests against *Iridomyrmex* runways.—Chlordane was used in a hand atomiser to spray portions of *Iridomyrmex* earth runways on palm-trunks. The spray was not strong enough to disintegrate these, but when they were inspected on the following day, only dead ants were found underneath them. The mist spray appeared to have percolated through the earth of the runways and to have been absorbed by it, so that it remained lethal to ants for some days. A week later there were no ants under the sprayed part of the runway, though very many in the unsprayed parts above and below it.

(ii) Tests on other Coreid bugs.—As *Amblyopelta* had almost disappeared from the Honiara/Kukum region since the war, tests were first made on other local Coreids. If the spray proved lethal to them, it would be fairly certain to kill *Amblyopelta*, too. Accordingly a number of examples of species of *Leptocorisa*, *Riptortus* and *Leptoglossus* were collected from leguminous plants at Kukum Agricultural Station, placed in cotton-mesh sleeve-cages with wooden bases and fed with beans. Tests were made in March–April 1953. The insecticides used were chlordane and DDT, prepared as in the earlier tests. Ten strokes of a "Rega" atomiser pump were made from various angles at a distance of about 3 ft. so that the spray would penetrate all parts of the mesh and contact the Coreids. Results were as follows:—

					Time taken to complete mortality (hrs.)	
					Chlordane	DDT
<i>Leptocorisa</i>	..	..	..	..	2-4	4-6
<i>Riptortus</i>	..	..	..	..	3-6	5-28
<i>Leptoglossus</i>	..	..	..	..	5-10	7-36

No bugs were dead in the control cages at the end of these tests.

Residual effects.—In order to determine the residual effects of these insecticides on the bugs further tests were conducted in which the bugs were put in the cages at five- and ten-day intervals after spraying in the same manner. Results were as follows:—

	Time taken to complete mortality (hrs.)			
	No. of days from spraying cages to insertion of bugs			
	5		10	
	Chlordane	DDT	Chlordane	DDT
<i>Leptocoris</i>	22-30	5-22	22-70	22-46
<i>Riptortus</i>	24-46	6-28	22-94	22-50
<i>Leptoglossus</i>	46-70	26-44	70 +	70-94

Note: In some cases these times are longer than those actually taken, as the bugs were left unwatched overnight. Controls: A few *Leptocoris* died in the control cages during the fourth day of test.

These tests show that both chlordane and DDT have a 100 per cent. lethal contact effect on the Coreids tested. Chlordane appeared to act more quickly on contact than DDT, killing all the test insects within 10 hours, whereas the latter took 36 hours. After twenty days the lethal effect of these sprayed cages was uncertain.

The egg-stage in *Amblypelta* lasts eight days. In the case of both insecticides, therefore, the residual effects seem to persist sufficiently long to kill any nymphs emerging from eggs laid by *Amblypelta* before spraying. In the case of chlordane, which appears to have a shorter residual effect than DDT, this is, however, not absolutely certain.

As the residual tests had shown a much shorter period of effectiveness for both insecticides than had been reported by other workers, it was thought that this might be due to using cotton-mesh for the cages. Accordingly, the tests were repeated, using cages made of plaited strips of *Pandanus* leaf. This had the additional advantage that it reproduced more nearly conditions in the palm-crowns.

During June-August 1953 a number of leaf-cage tests were made and these showed that the leaf surfaces were far more retentive of the spray than the cotton-mesh had been. Bugs placed in the cages 10, 20 and 30 days after the latter had been sprayed were all found dead within 48 hours. Even six weeks after the cages had been sprayed the effect proved just as lethal, all bugs dying within 48 hours. Chlordane and DDT gave similar results. There were no deaths in the leaf cages used as controls.

(iii) Tests on *Amblypelta*.—The writer's Gilbertese assistant, Tebau, was able to make tests similar to those described above on *Amblypelta* during a protracted stay at Ruavatu. The results were similar to those obtained with the other Coreids.

Future experiments.

As a result of the investigations outlined here, it had been intended that further tests of crown spraying should be carried out by Messrs. Lever's Ltd., after the author's departure. In the event it was decided to continue research and investigations along the lines started, and these are now in progress.

Summary.

Immature nutfall, caused by the Coreid, *Amblypelta cocophaga* China, was prevalent in the coconut plantations of the British Solomon Islands before the late war, and was increasing in extent and intensity. Good crops were borne by palms inhabited by colonies of *Oecophylla smaragdina* (F.), as this ant destroyed

Amblypelta; and the same was true, to a lesser extent, of another ant, *Anoplolepis longipes* (Jerd.). The smaller species, *Pheidole megacephala* (F.) and *Iridomyrmex myrmecodiae* Emery, did not destroy *Amblypelta* and consequently palms bearing these species suffered from nutfall. These non-beneficial ants were extending their areas of occupation and becoming dominant in the plantations of the Protectorate.

Attempts to control *Amblypelta* by introducing parasites from Indonesia, Queensland and Fiji have all proved ineffective, and so also have past efforts to change the balance of ant populations in the plantations in favour of the beneficial species.

After the war, it was noticed that certain plantations in Guadalcanal, which had suffered severely from nutfall for several years, were recovering and bearing well. In 1948, it was found that this recovery was correlated with changes in the ant populations, *Oecophylla* having occupied much of the area, displacing *Pheidole*, which had previously been dominant. The investigators concluded that this was due to ecological changes in the plantation undergrowth, resulting from neglect of cleaning and brushing during the war.

The present paper deals with a re-examination of the position in 1952-53. The author found a further improvement in the yield and an extension of the area of recovery on the plantation in question; *Pheidole* had completely disappeared, but in many parts *Oecophylla* had been driven back by *Anoplolepis*, which had now become the dominant ant. The only nutfall areas that remained here were occupied by *Iridomyrmex*.

A fuller examination of these and other plantations did not support the theory that nutfall recovery was due to ecological changes in the undergrowth, for these had occurred everywhere in the Protectorate during the war, yet on most other plantations yields had decreased, and *Pheidole* had greatly extended its pre-war area of occupation. The areas in which recovery had occurred were adjacent to wartime military installations that had been subject to regular weekly anti-malarial spraying from the air, and it is suggested that this had affected *Amblypelta*, both directly, and indirectly by having differentially affected the populations of *Pheidole* and *Oecophylla*. It seemed more likely that it had been caused by the long-sustained spraying programme carried out by the United States forces during and after the war.

Small-scale tests carried out with insecticidal sprays confirmed this theory: the harmful species, *Pheidole* and *Iridomyrmex*, were found to be very severely affected, while the beneficial ones, *Oecophylla* and *Anoplolepis*, suffered far less. In plots with mixed ant populations it was found possible to increase temporarily the number of palms occupied by beneficial species by spraying the palm-bases with insecticide. With the equipment available it was not possible to spray the boles and crowns: consequently, these trees were often reoccupied later by the harmful species *Iridomyrmex* from colonies in the crowns.

The sprays were also found to be fatal to Coreid bugs, both on contact and for a considerable residual period.

Acknowledgements.

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Mr. L. C. Thomas, the Managing Director of Messrs. Lever's Pacific Plantations Ltd., was extremely helpful in a number of ways, not only putting the

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References.

- FROGGATT, W. W. (1911). Pests and diseases of the coconut palm.—Sci. Bull. Dep. Agric. N.S.W., no. 2, 47 pp.
- LEVER, R. J. A. W. (1933). Notes on two Hemipterous pests of the coconut in the British Solomon Islands.—Brit. Solomon Is. agric. Gaz., **1**, no. 3 pp. 2-6.
- LEVER, R. J. A. W. (1935a). The Green Coconut Bug, *Amblypelta cocophaga* China.—Brit. Solomon Is. agric. Gaz., **3**, no. 2 pp. 6-7.
- LEVER, R. J. A. W. (1935b). The Green Coconut Bug *Amblypelta cocophaga* and induced immature nutfall in the coconut.—Brit. Solomon Is. agric. Gaz., **3**, no. 4 pp. 9-10.
- LEVER, R. J. A. W. & PHILLIPS, J. S. (1936). Further experiments with *Amblypelta* and immature nutfall.—Brit. Solomon Is. agric. Gaz., **3**, no. 4, suppl. pp. 4-5.
- O'CONNOR, B. A. (1949). Premature nutfall of coconuts in the British Solomon Islands Protectorate.—Agric. J. Fiji, **20**, pp. 27-29.
- O'CONNOR, B. A. (1950a). Premature nutfall of coconuts in the British Solomon Islands Protectorate.—Agric. J. Fiji, **21**, pp. 21-39.
- O'CONNOR, B. A. (1950b). *Trichopoda pennipes* F. in Fiji and the British Solomon Islands.—Agric. J. Fiji, **21**, pp. 63-71.
- PHILLIPS, J. S. (1940). Immature nutfall of coconuts in the Solomon Islands.—Bull. ent. Res., **31**, pp. 295-316.
- PHILLIPS, J. S. (1941). A search for parasites of Dasynine bugs in the Netherlands Indies.—Trans. R. ent. Soc. Lond., **91**, pp. 119-144.
- SIMMONDS, H. W. (1925). Pests and diseases of the coconut palm in the islands of the South Pacific.—Bull. Dep. Agric. Fiji, no. 16, 31 pp.
- TOTHILL, J. D. (1929). A reconnaissance survey of agricultural conditions in the British Solomon Islands Protectorate.—17 pp. Suva, Fiji.
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FIG. 1. Nutfall area at Ruavatu showing creeping cover crop round bases of palms; all trees colonised by *Pholidole*.



FIG. 2. Swollen stem of epiphyte, cut open to show nest of *Iridomyrmex*.

THE GEOGRAPHICAL DISTRIBUTION OF BLOWFLIES IN GREAT BRITAIN.

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(PLATES X & XI.)

Among the CALLIPHORINAE is a group of flies the members of which will on occasion lay eggs on living sheep. Until the introduction of the modern insecticides the resulting cutaneous myiasis represented one of the major sources of loss to the sheep farmer.

Certain anomalies were observed in the species pattern of myiasis for different regions of Britain (MacLeod, 1943), and this led to an examination of the distribution of the different members of the myiasis group. It was immediately apparent, however, that the existing records of distribution did not provide a safe basis for assessing this; for certain areas no entomofaunistic survey had been made, and in the case of many published records only the unexpected or unusual occurrence was recorded, common species being omitted. A survey was therefore made, in 1953, of the distribution of the carrion-attracted blowflies. The method was that simultaneous trappings were made over Britain, the circumstances and conditions of the trappings being so far as possible standard.

The quantitative analysis of the results, in relation to season, vegetation, altitude, etc., must await confirmatory or extended trapping in those areas poorly represented in the 1953 survey, but the qualitative results, on geographical distribution of the different species, are of sufficient interest to justify their presentation in this preliminary communication.

Existing Records of Distribution.

As an introduction to the survey results, a list of available existing records has been compiled, based on published Diptera lists, supplementary lists of private collections, and records supplied by public museums. In this connection we would like to make acknowledgement particularly of the invaluable help received from the Entomological Department of the British Museum (Natural History). Dr. F. I. van Emden, of the Commonwealth Institute of Entomology, and his colleague, Mr. R. L. Coe, of the British Museum (Natural History), had already prepared an indexed list of references and very kindly made this available to us, thus sparing us the greater part of the labour of collation.

TABLE I.

Sources of Distribution Records.

Local Lists

1. Audcent, H. L. F. (1949-50). Bristol insect fauna—Diptera.—*Proc. Bristol Nat. Soc.*, **27**, pp. 409-470; **28**, pp. 45-182.
2. Bertram, D. S. & others. (1939). A natural history of Canna and Sanday, Inner Hebrides.—*Proc. R. phys. Soc. Edinb.*, **23**, pp. 1-72.
3. Hincks, W. D. (1953). The entomology of Spurn Peninsula. XII. Diptera.—*Naturalist, Lond.*, no. 847, pp. 159-167.

4. Britten, H. & others. (1914-48). 1st-28th Rep. Lancs. Chesh. Fauna Comm., 1914, 1915, 1925-48.
- Britten, H., Newton, P. & Wild, S. V. (1941). The natural history of the Ballast Hole, Sinderland, Cheshire.—Northw. Nat., **16**, pp. 41-56, 183-193.
- Britten, H. (1943). *Lucilia ampullacea* Vill. and toads.—Northw. Nat., **18**, p. 109.
- 4b. Bury, H. (1916). Preliminary list of Diptera.—Lancs. Chesh. Nat., **9**, pp. 129-138.
5. Bradley, R. C. (1898). *Cynomyia alpina*, Zett., in Warwickshire.—Ent. mon. Mag., **34**, p. 63.
6. Carr, J. W. (1916). The invertebrate fauna of Nottinghamshire.—618 pp. Nottingham, Bell.
- Carr, J. W. (1935). The invertebrate fauna of Nottinghamshire. Supplement.—287 pp. Nottingham, Bell.
7. Collin, J. E. (1938). Diptera.—In Darby, H. C. Ed. A scientific survey of the Cambridge district, pp. 72-74.
8. Collin, J. E. & Wainwright, C. J. (1934). Some Diptera collected in the south of England in 1930-33.—J. Soc. Brit. Ent., **1**, pp. 17-28.
9. Cragg, J. B. & Ramage, G. R. (1945). Chemotropic studies on the blow-flies *Lucilia sericata* (Mg.) and *Lucilia caesar* (L.).—Parasitology, **36**, pp. 168-175.
10. Cragg, J. B. & Thurston, B. A. (1950). The reactions of blowflies to organic sulphur compounds and other materials used in traps.—Parasitology, **40**, pp. 187-194.
11. Edwards, F. W. (1934). Diptera on Grassholm Island, Pembrokeshire.—J. Soc. Brit. Ent., **1**, pp. 33-34.
12. Fordham, W. J. (1945). A preliminary list of the Diptera of Northumberland and Durham (excluding the Cecidomyiidae).—Trans. nat. Hist. Soc. Northumb., (N.S.) **7**, pp. 197-265.
13. Graham-Smith, G. S. (1916). Observations on the habits and parasites of common flies.—Parasitology, **8**, pp. 440-544.
14. Green, A. A. (1951). The control of blowflies infesting slaughter-houses. I. Field observations of the habits of blowflies.—Ann. appl. Biol., **38**, pp. 475-494.
15. Grimshaw, P. H. (1898). Nottinghamshire Diptera: a preliminary list.—Naturalist, Lond., **1898**, pp. 89-103.
16. Grimshaw, P. H. (1898). Lincolnshire Diptera: a preliminary list.—Naturalist, Lond., **1898**, pp. 157-170.
17. Grimshaw, P. H. (1899). Diptera Scotica. I. Perthshire.—Ann. Scot. nat. Hist., **1899**, pp. 84-91, 161-164.
18. Grimshaw, P. H. (1900). Diptera Scotica. II. Inverness-shire.—Ann. Scot. nat. Hist., **1900**, pp. 18-30.
19. Grimshaw, P. H. (1903). Diptera Scotica. III. The Forth district.—Ann. Scot. nat. Hist., **1903**, pp. 154-166.
- Grimshaw, P. H. (1906). Diptera Scotica. V. The Forth district (second supplement).—Ann. Scot. nat. Hist., **1906**, pp. 154-161.
20. Grimshaw, P. H. (1905). Diptera Scotica. IV. Orkney and Shetland.—Ann. Scot. nat. Hist., **1905**, pp. 22-35.
21. Grimshaw, P. H. (1905). On the Diptera of the Flannan Islands.—Ann. Scot. nat. Hist., **1905**, pp. 218-220.
22. Grimshaw, P. H. (1906). The Diptera of Fair Isle.—Ann. Scot. nat. Hist., **1906**, pp. 207-209.
23. Grimshaw, P. H. (1907). On the Diptera of St. Kilda.—Ann. Scot. nat. Hist., **1907**, pp. 150-158.
24. Grimshaw, P. H. (1914-16). Diptera Scotica. VI. The western isles.—Scot. Nat., **1914**, pp. 205-212, 234-236, 258-262; **1915**, pp. 276-281; **1916**, pp. 115-119, 134-138. (See **1915**, p. 276.)
25. Grimshaw, P. H. (1901). Order Diptera (except Tipulidae).—In Elliot, G. F. S., Laurie, M. & Murdoch, J. B. Fauna, flora and geology of the Clyde area, pp. 258-266. Glasgow, Brit. Ass. Handb.
26. Haines, F. H. (1936). List of insects found near Aviemore, Inverness-shire, from June 20th to July 2nd, 1933.—J. Scot. Brit. Ent., **1**, pp. 131-141.
27. Harwood, B. S. (1932). The Diptera of Suffolk. First supplement.—Trans. Suffolk Nat. Soc., **2**, pp. 36-51.
28. Edwards, F. W. & Collin, J. E. (1932). A revised list of the Diptera of St. Kilda.—Ent. mon. Mag., **68**, pp. 263-266. (St. Kilda papers, 1931. Oxford, Univ. Pr., 1937.)
29. Luff, W. A. (1894-1908). Insects of Herm, Jethou, Guernsey, Alderney and Jersey.—Rep. Guernsey Soc. nat. Sci., 1894, 1895, 1899, 1908.
30. Anon. (1926-31). Rep. Marlborough Coll. nat. Hist. Soc., 1926-31. (See 1927 and 1928.)
31. Morison, G. D. (1937). Some results of trapping the sheep blowfly (*Lucilia sericata*, Meigen).—Scot. J. Agric., **20**, pp. 123-134.
32. Morley, C. & Atmore, J. (1915). The Diptera of Norfolk and Suffolk.—Trans. Norfolk Norw. Nat. Soc., **10**, suppl., 180 pp.
33. Morey, F. (1909). A guide to the natural history of the Isle of Wight.—560 pp. Newport, I.O.W.

34. Naturalist, The. (Field notes, contributed by members of the Yorkshire Naturalists' Union and others, 1927, p. 299; 1934, p. 10; 1935, p. 233; 1948, pp. 12, 161.)
36. Palmer, M. G. *Ed.* (1946). The flora and fauna of the Ilfracombe district of North Devon.—266 pp. Exeter, Ilfracombe Field Club.
37. Parmenter, L. (1938). The survey of Limpsfield Common. Diptera.—*Lond. Nat.*, **1937**, pp. 61–64.
38. Parmenter, L. (1944). Collecting Diptera on the Norfolk Broads.—*J. Soc. Brit. Ent.*, **2**, pp. 208–213.
39. Parmenter, L. (1950). Diptera in Northumberland.—*Naturalist, Lond.*, **1950**, pp. 56–59.
40. Parmenter, L. (1951). Flies taken in a light trap.—*Ent. mon. Mag.*, **87**, pp. 249–250.
41. Pugh, C. H. W. (1928, 1935, 1941). *Rec. Caradoc Severn Valley Fld Cl.*, 1928, 1935, 1941.
42. Smith, K. G. V. (1950). Diptera of Skokholm and Grassholm.—*Rep. Skokholm Bird Obs.*, 1950, pp. 24–28.
43. Thornley, A. (1935). A provisional list of Cornish insects. Part II. Diptera—Syrphidae, Tachinidae and Muscidae.—*Trans. Soc. Brit. Ent.*, **2**, pp. 87–114.
44. Victoria Histories of the Counties of England. Oxford University Press. The counties of:—Warwickshire, Cambridgeshire, Oxfordshire, Essex, Derbyshire, Cumberland, Cornwall, Hampshire, Durham, Devon, Leicestershire, Kent, Herefordshire, Staffordshire, Yorkshire.
46. Wardle, R. A. (1927). The seasonal frequency of Calliphorine blowflies in Great Britain.—*J. Hyg., Camb.*, **26**, pp. 441–464.
47. White, J. H. (1947). A preliminary list of the Lincolnshire Diptera.—*Trans. Lincs. Nat. Un.*, **11**, pp. 163–175.
48. Wingate, W. J. (1906). A preliminary list of Durham Diptera, with analytical tables.—*Trans. nat. Hist. Soc. Northumb.*, (N.S.) **2**, 416 pp.
49. West, W. (1909). Diptera.—*In* Grinling, C. H., Ingram, G. A. & Polkinghorn, B. C. *Ed.* A survey and record of Woolwich and west Kent, pp. 421–430.
50. Yerbury, J. W. (1913). A list of the Diptera met with in Wester Ross . . .—*Scot. Nat.*, **1913**, pp. 13–17.
51. Yerbury, J. W. (1918). The Diptera of Glamorgan.—*Trans. Cardiff Nat. Soc.*, **51**, pp. 48–79.

Addenda.

35. Williamson, K. & Cowin, W. S. (1941). Manx entomology, 1940.—*Naturalist, Lond.*, **1941**, pp. 240–245.
67. Parmenter, L. (1954). City bombed sites survey. The flies of the Cripplegate bombed site, City of London.—*Lond. Nat.*, no. 33, pp. 89–100.

General Lists

52. Day, C. D. (1948). British Tachinid flies.—150 pp. Arbroath, Buncle. (Reprinted from *Northw. Nat.*, **21–22** (1946–47).)
53. Richards, O. W. (1926). Notes on the British species of *Lucilia* (Diptera) (with a supplementary note by J. E. Collin).—*Trans. ent. Soc. Lond.*, **74**, pp. 255–260.
54. Wainwright, C. J. (1928–40). The British Tachinidae (Diptera).—*Trans. ent. Soc. Lond.*, **76** (1928), pp. 139–254. First supplement.—*Ibid.*, **80** (1932), pp. 405–424. Second supplement.—*Ibid.*, **90** (1940), pp. 411–448.

Unpublished Records from Collections

55. Dr. C. D. Day, Dorchester. Records from his private collection.
56. Mr. W. K. Ford, Keeper of Department of Invertebrate Zoology, City of Liverpool Public Museums.
57. Mr. C. W. Hunt, Keeper of Biology, City of Leicester Museum and Art Gallery.
58. Dr. F. I. van Emden, British Museum (Natural History), South Kensington.

Incidental Records

59. Graham-Smith, G. S.* (1914). Flies in relation to disease: non-bloodsucking flies.—2nd edn., 389 pp. Cambridge Univ. Pr.
60. Haddow, A. J. & Thomson, R. C. Muirhead. (1937). Sheep myiasis in south-west Scotland, with special reference to the species involved.—*Parasitology*, **29**, pp. 96–116.
61. MacDougall, R. S. (1909). Sheep maggot and related flies: their classification, life-history and habits.—*Trans. Highl. agric. Soc. Scot.*, **21**, pp. 135–174.
62. MacLeod, J. (1943). A survey of British sheep blowflies.—*Bull. ent. Res.*, **34**, pp. 65–88. (Also unpublished further details. See footnote to Table 2).
63. Morison, G. D. (1942). Sheep strike by the fly, *Phormia terrae-novae* R.-D., in north-east Scotland.—*Nature, Lond.*, **149**, p. 358. (Locations cited in 62, from private communication.)

64. Parmenter, L. (1951). Flies on the stinkhorn fungus, *Phallus impudicus* Pers.—Ent. Rec., **63**, pp. 59–60.
65. Ratcliffe, F. N. (1935). Observations on the sheep blowfly (*Lucilia sericata* Meig.) in Scotland.—Ann. appl. Biol., **22**, pp. 742–753.
66. Blackford Laboratory. Unpublished records.

The sources are listed in Table I, and include local lists, lists on a national basis, unpublished records, and also “incidental” records, *i.e.*, where a single species, or group, is referred to in a report of work not primarily faunistic. Unlike collectors’ records, these latter have obviously no comparative value; they have nevertheless helped in many cases to fill in gaps in recorded distribution.

In Table II the records for each of the carrion-infesting species are grouped by vice-counties. The code numbers refer to the sources given in Table I, those from the “incidental” category being distinguished by italic type.

Notes on Existing Records.

The recorded distribution of species, as indicated in Table II, is discussed later in relation to our survey results, but the following comments on the literature may usefully be made at this stage.

Nomenclature.

The sources listed in Table I cover a period during which there have been many changes in classification and naming. As a result, a named specimen in an early list may be cited under a different name in a list compiled by a later worker; also some of the older, as yet unrevised, records can safely be identified with currently recognised species. As an example of the latter, *Cynomyia alpina* (Zett.) of Bradley (5) is almost certainly *Acrophaga subalpina* (Ringdahl). Following van Emden (1954) for current nomenclature, we have interpreted all such records where the synonymy is unambiguous.

In the case of the genera *Calliphora* and *Lucilia*, the changes have occasionally complicated the position. Until 1928, British *Calliphora* appear to have been accepted as either *C. erythrocephala* (Mg.) or *C. vomitoria* (L.); thus Wainwright (54) records having collected in 1919 a specimen of *C. loewi* End. which he did not identify as such until 1928. The less readily detectable *C. uralensis* Villen. was not separated in existing collections until 1932, when Collin recognised a single specimen in an old collection; the record was not confirmed by further collection until 1938.

The classification of the *Lucilia* species was so drastically revised as a result of the work of Richards & Collin (53) in 1926 that in the case of many older records unsupported by specimens it is impossible to say to what species the record refers. The females of the *L. caesar* group (*L. caesar* (L.), *L. illustris* (Mg.) and *L. ampullacea* Villen.), still present difficulty, and in certain records an identification of *L. caesar* is either stated or implied as being only to the group. Where such records arise from accounts of sheep myiasis, they can fairly safely be attributed to *L. caesar* or *L. illustris*, since *L. ampullacea* is believed not to strike sheep.

The sources for existing records for Scotland preponderantly antedate both the recognition of the less common *Calliphora* species, and the critical revision of the genus *Lucilia*, so that the Scottish distribution picture presented by Table II is of little value for either of these genera.

Vice-county distribution maps.

In collating existing records, with their varying degree of precision in designation of localities, some arbitrary grouping is unavoidable. Territorial units based on ecological considerations are ideally desirable, but since much of the published

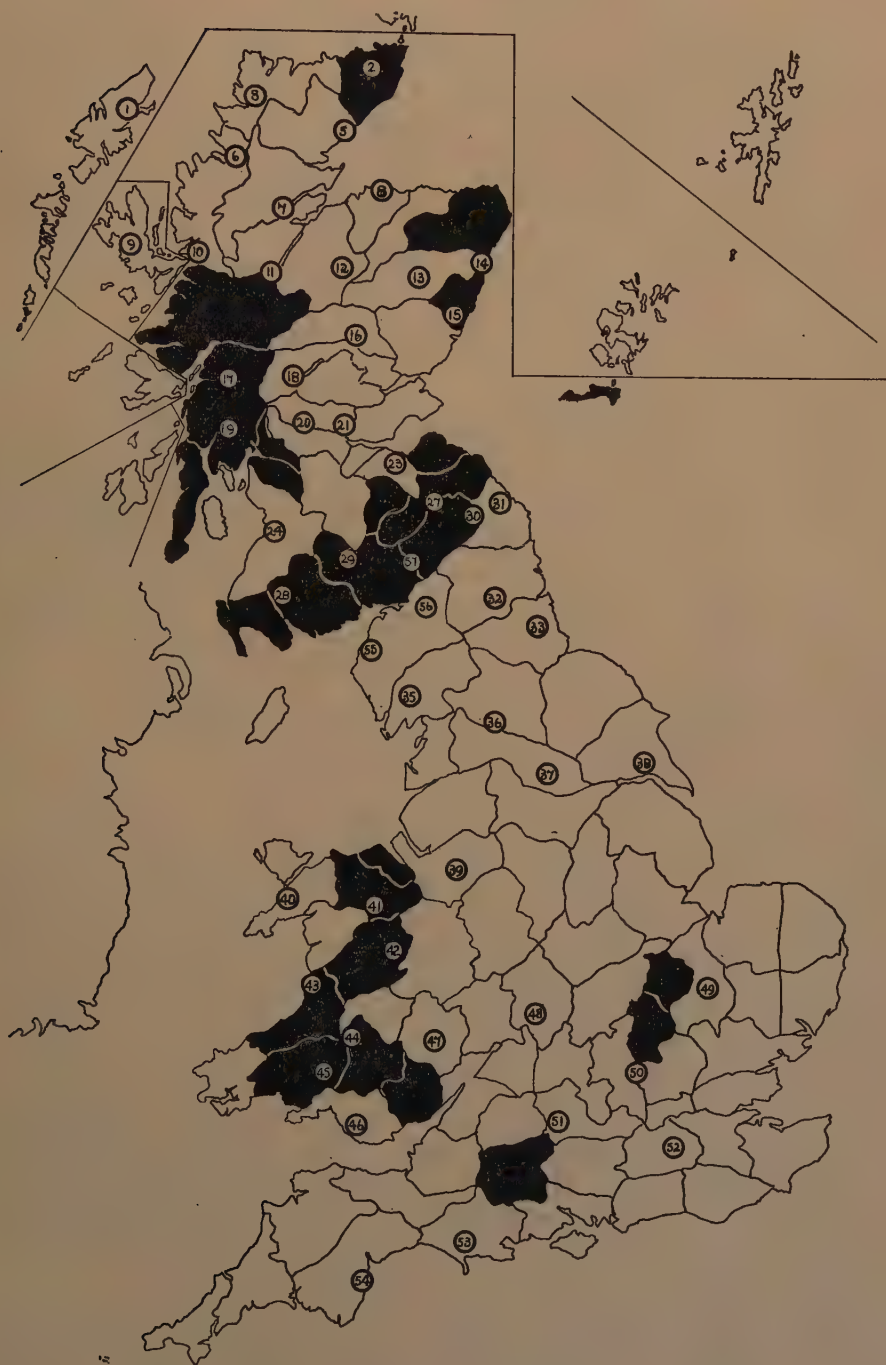


Fig. 1.—The vice-counties blacked-in are those for which there are no Diptera lists on record. The positions of the survey stations are indicated by their code numbers (Table III) in circles.

TABLE II.

Recorded distribution.

(Code numbers in *italic type* in this Table refer to "Incidental Records" in Table I.)

Vice-county	<i>L. servicata</i>	<i>L. richardsi</i>	<i>L. caesar</i>	<i>L. illustris</i>	<i>L. ampullacea</i>	<i>L. silvarum</i>	<i>P. terrae novae</i>	<i>C. erythroccephala</i>	<i>C. vomitoria</i>	<i>C. loewi</i>	<i>C. uralensis</i>	<i>A. subalpina</i>	<i>Cyn. mortuorum</i>
West Cornwall	43, 58, 54	43	43, 44, 56, 58	43, 56	43, 58	43	43	43, 44, 58	43, 44				
East Cornwall	43	43	43, 44	43	58	43	43	43, 44	43, 44				44
South Devon	62		44, 58, 53, 62*	62				44, 57	44, 57				
North Devon	62		36, 44, 58	55				36, 44, 58	36, 44, 58				44
South Somerset	56, 62												
North Somerset	1	1	1	1	1	1	1	1	1				1
North Wilts.	30		30					30	30				
South Wilts.													
Dorset	55	55, 58	55	55	52, 55	55	55	55, 58	55				55
Isle of Wight	33	56, 58	33, 58	55				33	33				
Hants., South	58, 62	56, 58	44, 58, 53		54, 58, 53		44, 55	44, 58	44, 58				44
Hants., North	62	8, 58	8, 44,	8			44	44	44				44
			55, 58										
West Sussex	62		56, 58						58				
East Sussex	57, 58		57, 58	58	58	58		57	57, 58				58
East Kent	61, 62	56, 58	44, 61, 62	62				44, 58					56
West Kent	62		44, 49, 58	58	64	49	44, 49, 58	44, 49, 58	49, 58				
Surrey	44, 58, 62	58	57	58		58	44	37, 58, 64	58, 64				44
South Essex	44	58	44			58	44	44	44				44
North Essex	44		44			58	44	44	44				44
Herts.	62		62	62			58	62					58
Middlesex	14, 21		14	14, 58, 21		55	14, 58, 21	14, 58, 21	14, 58, 21				
Berks.		53, 58	53	53	53, 54, 58								
Oxford	44, 53,	44, 53,	44, 53,	44, 53,	44, 53,	44, 53,	44	44, 53,	44				44
	56, 58	56, 58	56, 58	56	54, 56	58		58					

* Identification only to "*L. caesar* group", i.e., the specimen may have included *L. caesar* and/or *L. illustris*.

[illegible]

Mid-Perth ..	62	62*	62*	17	17	17	58	56, 58
North Perth ..	60, 61, 62	60, 62*	62*	58	58	58	58	55, 58
Angus ..	61	31, 62*	31, 62*	63	62, 63	63	55	31, 55, 56, 58
Kincardine ..	31, 61, 62			63	63	65	58	58
South Aberdeen ..	62			63	63	61	54, 55, 58	18, 55, 58
North Aberdeen ..	62			58	26, 58, 62	18	58	58
Banff ..	62			62	62	62	58	58
Moray ..	61			62	62	62	58	58
East Inverness with Nairn ..	18, 62	18, 26, 58, 62*	62*	62	62	62	58	58
West Inverness with North Argyll ..	62	60, 62	62	62	62	62	58	58
Argyll (Main)	60, 61, 62	60, 62	62	62	62	62	58	58
Dumbarton (West)	60	25, 60	60	25, 60	25	25	55	25
Cantire ..	60	60	60	60	60	60	55	25
Islay and Jura ..	24, 62	24	62*	24	24	24	55	24
Mull, etc. ..	2, 62	62	62*	62	62	62	55	24
Skye, etc. ..	62	2, 62	62*	62	62	62	55	24
West Ross ..	61, 62	62*	62*	62	62	62	55	24
East Ross ..	62	62*	62*	62	62	62	55	24
East Sutherland ..	62	62*	62*	62	62	62	55	24
West Sutherland ..	61, 62	66	66	66	66	66	55	24
Caithness ..	24, 62	66	66	66	66	66	55	24
Outer Hebrides ..	29	29	29	29	29	29	55	24
Orkney ..	29	29	29	29	29	29	55	24
Shetland ..	29	29	29	29	29	29	55	24
Channel Isles ..	29	29	29	29	29	29	55	24

work is already grouped in terms of politico-social boundaries it is more convenient to accept the conventional territorial units, even though these have sometimes little or no ecological basis. The vice-county system, though more popular with botanists than zoologists, offers some degree of compromise, and in its interim form (New Naturalist Series scheme, Turrill, 1953), has been chosen as the most practicable form of grouping to suit our purpose. The description of species distribution by vice-counties has, however, certain obvious limitations, well recognised in related fields of work. Vice-counties for which there are no Diptera lists on record must obviously be disregarded in compiling a distribution map. A difficulty is that the chance recording of, say, some unusual or interesting capture may exclude from the "completely unsurveyed" territory a vice-county for which there are no other records. To reduce this objection we have separated, in our sources, a category of "incidental" records. Any vice-county for which there is a record apparently arising as a result of the collection of insects as a major object is regarded as worked territory. A record which originates as incidental to other work, *e.g.*, in medical or veterinary case histories, descriptions of predator-prey or host-plant relationships, etc., does not in itself classify the vice-county concerned as "worked" territory. The "unworked" territory, on the above basis, is shown in fig. 1 as blacked-out vice-counties. It will be noted that it is mainly (though not entirely) confined to hill country.

Even in a map restricted to worked territory, however, marked differences occur in the frequency and the comprehensiveness of the Diptera lists for vice-counties; this may result in quite unrealistic distribution pictures. Thus, a vice-county may be classified as worked in virtue of a single collection, and even this may be cursory. Secondly, even an exhaustive list, though comprehensive for the specified locality, is not necessarily representative of the vice-county, for which it may constitute the only record. As examples of the resulting unrealistic representation, we may cite from our Table II the vice-counties North Somerset and South Gloucester, both of which class as "worked" on the strength of a single source—Audcent (1)—who collected in a limited area around Bristol. Further, since the area lies at the junction of the two vice-counties, those records where Audcent has not stated the precise locality must be attributed to both vice-counties.

Another aspect of the unrealistic element in vice-county maps is exemplified by those vice-counties represented by collections in quite atypical localities, *e.g.*, the Hebrides mainly by St. Kilda (23 and 28) and the Flannan Isles (21), and Pembroke only by Skokholm-Grassholm (11 and 42).

Yet another difficulty is the "blanket" type of locality record, *e.g.*, "Forth District" (19) which includes four vice-counties, and Yorkshire (44), covering five vice-counties, although it should be mentioned that in these sources the precise locality is given for many of the species.

The Bait-trap Survey.

Fifty five stations were selected for the first survey. Additional stations have since been brought in, but the results from these are not yet available. The stations were chosen without regard to land use, the choice for any given region being primarily dependent on presence of suitable facilities. In four cases arrangements broke down; fifty of the remaining fifty one are listed in Table III, in numerical order of their reference numbers. Their distribution is illustrated in fig. 1.

Where possible, an official or semi-official centre was chosen. The first choice was an agricultural institute, a college farm, or an A.R.C.-affiliated or other officially administered farm. Failing such, a biological research centre, or centre for furthering educational field activities, was sought, but in several regions,

TABLE III.
1953 Survey stations.

Ref. no.	Station	Location	Operator
1.	Lewis	Village of Balallan, near Loch Erisort	Crofter
2.	Halkirk	Arable farm, north of Stemster Loch	Farmer
3.	Reay Forest	Near Lochmore, West Sutherland	Farm Manager
5.	Helmsdale	Coastal strip at Loth	Private
6.	Ullapool	Keanchulish	Factor
7.	Strathpeffer	Golf course, above the town	Greenkeeper
8.	Elgin	Aldroughty Demonstration Farm	Farm Manager
9.	Skye	Farm near mouth of Loch Harport	Farmer
10.	Lochalsh	School of Further Education Farm, Balmacara	Farm Manager
11.	Fort Augustus	Common grazing west of the town	Smallholder
12.	Strathspey	Scottish Centre of Outdoor Training, Loch Morlich	Warden
13.	Deeside	College Demonstration Farm, Blanastraid	Farm Manager
14.	Craibstone	North of Scotland College Farm, Aberdeen	V.I.O.
15.	Glensaugh	Hill Farming Research Organisation Farm, near Cairn o' Mount, Kincardineshire	Recorder
16.	Pitlochry	Brown Trout Research Station, Faskally	Research Staff
17.	Glen Etive	D.O.A.S. Farm, near Rannoch Moor	Farm Manager
18.	Killin	Hill farm, west of the town	Farmer
19.	Lepinmore	Hill Farming Research Organisation Farm, Lepinmore, on Loch Fyne	Recorder
20.	Aberfoyle	Bracken Eradication Experimental Farm, north of Lake of Menteith	Shepherd
21.	Dollar	Farm beside the town	Farmer
23.	Edinburgh	School of Agriculture, Bush Estate	A.D.R.A.
24.	Ayr	College Farm, Auchincruive	Entom. Dept. Assistant Farm Manager
27.	Lauder	Hill farm, east of the town	Farmer
28.	Bargrennan	Galloway. Hill farm, north of the village	Farmer
29.	Forest of Ae	Forestry Commission land. Near Loch Ettrick in Nithsdale	Private
30.	Sourhope	Hill Farming Research Organisation Farm, near Yetholm, north of Cheviot	Recorder
31.	Lowick	Lowland farm, north of Wooler	Farm Manager
32.	Tyne Gap	Near Allerwash	Private
33.	Durham	Near University Science Laboratories	Zoology Dept.
35.	Windermere	Freshwater Biological Association Laboratory	Laboratory Steward
36.	Malham Tarn	Council for Promotion of Field Studies Centre	Asst. Warden
37.	Leeds	University Farm, near Tadcaster	Farm Director
38.	Beverley	Dairy farm, near Bishop Burton	Farmer
39.	Cheshire Gap	Salterford School, near Holmes Chapel	Headmaster
40.	Caernarvon	Glynliffon Farm Institute	Principal
41.	Corwen	A.R.C. Hill Sheep Experimental Farm	Farm Manager
42.	Welshpool	Dairy farm, east of the town	Farmer
43.	Aberystwyth	University Farm	Farm Manager
44.	Brecon	Hill farm, above Llanwrtyd Wells	Farmer
45.	Llandilo	Carmarthen Farm Institute	Deputy Principal
46.	Glamorgan	A.E.C. Demonstration Farm, near Tregroes	Farm Manager
47.	Hereford	Rosemaund Experimental Husbandry Farm	Farm Director
48.	Stratford-on-Avon	Grassland Research Institute	Farm Manager
49.	Cambridge	School of Agriculture Farm	Entom. Dept.
50.	Berkhamsted	Cooper Technical Bureau. Berkhamsted Hill Laboratory	Entom. Dept.
51.	Compton	A.R.C. Research Station	Research Staff
52.	Weybridge	M.A.F. Veterinary Laboratory	Entom. Dept.
53.	Dorchester	Dorset Farm Institute	Warden
54.	Seale Hayne	Agricultural College	Entom. Dept.
55.	Cockermouth	Hill farm, east of the town	Farmer
56.	Carlisle	Crosby Field Laboratory, north of the Eden	
57.	Teviothead	Mossaul Valley experimental area	

particularly in the hill country, no suitable centre existed, and it was necessary to enlist the help of private individuals.

At each station, the local blowfly population was to be sampled on three occasions, mid-June, late July and mid-September, to cover seasonal differences in the species pattern. To compensate to some degree for interfering effects from local weather, each trapping period was to last for seven consecutive days.

For ecological reasons it was desirable that the siting of the traps be as comparable as possible, that the traps themselves be all of the same type, and the bait used be standard. A simple wire-gauze balloon trap (Pl. X, fig. 1) was used, baited with freshly killed rabbit. Four traps were to be employed at each station. They were to be emptied, and the bait renewed, twice during the week. Thus, from each station three collections from each of four traps would be available for each trapping period.

The problem of comparable siting provided the major difficulty. A trap site—an "activity arena" in fly territory—was arbitrarily defined as a structurally identifiable area of a minimum of 50 yards', and preferably 100 yards', diameter. The four sites were required to conform to categories ideally defined as follows. First, the site was classified as "sheltered", by adjacent topographic masses, or "exposed". Within these broad categories an arena was classified by its vegetation as "bare" or "cover" according to whether flies, in moving about, had necessarily to fly above the vegetation tops, *e.g.*, as with short sward or compact continuous high vegetation, or could move under the canopy of open vegetation, *e.g.*, in interrupted gorse or sparse bracken.

This concept of a miniature forest canopy relates purely to the present specialised study; it is not to be confused with the low or high canopy layers proposed by Elton & Miller (1954) as ecological categories of woodland habitat. In a woodland formation type, our "cover" and "bare" categories would, in fact, both be included in the "field layer" of these authors.

The concept of adequate aerial activity space under or among cover could in fact seldom be fully realised, one reason being the seasonal change in the field layer between June and September, and in many cases the "cover" was, at best, inadequate. Similarly, compromises for the "bare" categories had occasionally to be accepted. The topographic characters could usually be satisfied, though in some cases, in flat terrain, sheltering topographic masses had to be represented by buildings, thick hedges, or woods.

At each station four sites were selected, representative of the region, but with the above defined habitat conditions: Shelter, with cover, *i.e.*, protected from wind and sun (*e.g.*, Pl. XI, fig. 3; Pl. X, fig. 4); Shelter, bare, *i.e.*, a sheltered position exposed to the sun (*e.g.*, Pl. XI, fig. 2 (central hollow)); Exposed, with cover, *i.e.*, a position open to the sweep of the wind, but with rough cover (*e.g.*, Pl. XI, fig. 2 (mid-distance slopes)); Exposed, bare, *i.e.*, open to wind and sun (*e.g.*, Pl. X, figs. 2 & 3).

In all but two stations the sites were selected by us, and although obviously not always comparable between stations, sufficiently reflected the range of habitat available to make it probable that all the blowfly species present in the area had an opportunity of being taken.

As indicated above, more than one type of site is exhibited in Plate XI, fig. 2. Other general habitats that include several types of site are illustrated in Plate XI, figs. 1 and 4. The scale of Plate XI, fig. 4, is too small to show detail, but bracken in the foreground provides "exposed cover" and the corrie a mixture of "shelter, bare" and "shelter, cover".

Notes on the Survey.

Before the distributions of the different species are analysed, certain points relevant to the results given in Table IV call for comment.

TABLE IV.

Survey results.

Station	Total Calliphorines	<i>L. sericata</i>	<i>L. richardsi</i>	<i>L. caesar</i>	<i>L. illustris</i>	<i>L. ampullacea</i>	<i>L. silvarum</i>	<i>P. terraenovae</i>	<i>C. erythrocephala</i>	<i>C. vomitoria</i>	<i>C. uralensis</i>	<i>C. loewi</i>	<i>A. subalpina</i>	<i>Cyn. mortuorum</i>
Lewis ..	873			+				+	+	+	+			+
Halkirk ..	408			+	+			+	+	+	+	+		+
*Reay Forest	243			+	+			+	+	+	+	+		
Helmsdale ..	675	+		+	+		+	+	+	+	+	+		+
Ullapool ..	463	+		+	+			+	+	+	+			
Strathpeffer ..	2893	+		+	+	+		+	+	+				
Elgin ..	2915			+	+	+		+	+	+				
Skye ..	157			+					+	+				
Lochalsh ..	220			+	+			+	+	+				
*Fort Augustus	338			+	+		+	+	+	+				
Strathspey ..	216							+	+	+			+	
Deeside ..	2604	+	+	+	+			+	+	+				
Craibstone ..	987			+	+			+	+	+				
Glensaugh ..	438			+	+				+	+			+	
Pitlochry ..	2637	+		+	+	+	+	+	+	+				
Glen Etive ..	815			+				+	+	+			+	
Killin ..	35			+		+			+	+				
*Lephinmore ..	1720			+	+	+	+		+	+		+		
Aberfoyle ..	752			+	+	+	+		+	+				
Dollar ..	525	+		+	+	+		+	+	+				
Edinburgh ..	3021			+	+	+	+	+	+	+		+		
*Lauder ..	157			+	+	+	+	+	+	+				
Ayr ..	1330			+	+	+	+	+	+	+				
Bargrennan	452			+	+	+			+	+				
Forest of Ae	486	+		+	+	+		+	+	+			+	
Teviothead ..		+		+	+			+	+	+		+		
*Sourhope ..	61			+					+	+				
Lowick ..	1275			+	+			+	+	+		+		
Cockermouth	1035			+	+	+		+	+	+		+	+	
Carlisle ..	4573	+		+	+	+	+	+	+	+				
Tyne Gap ..	1380	+		+	+	+	+	+	+	+				
Durham ..	1566	+	+	+	+	+	+		+	+			+	
Windermere	1309			+	+	+	+		+	+			+	
Malham Tarn	925			+	+				+	+		+		
Leeds ..	1045	+	+	+	+	+	+		+	+			+	
Beverley ..	1774	+	+	+	+	+	+	+	+	+				
Cheshire Gap	1652	+		+	+	+	+	+	+	+				
Caernarvon ..	1331	+		+	+	+	+		+	+			+	
*Corwen ..	871			+	+			+	+	+				+
Welshpool ..	1543	+		+	+	+	+		+	+			+	
Aberystwyth	514	+	+	+	+	+	+		+	+				
*Brecon ..	156			+	+	+			+	+				
Llandilo ..	368	+		+	+	+	+		+	+				
Glamorgan	187	+		+	+			+	+	+				
Hereford ..	815	+	+	+	+	+	+		+	+				+
Stratford ..	557	+	+	+	+			+	+	+				+
Cambridge ..	2293	+	+	+	+	+	+		+	+				
Berkhamsted	1100	+	+	+	+	+	+		+	+				+
Compton ..	2633	+	+	+	+	+	+	+	+	+				+
Weybridge ..	1516	+	+	+	+	+	+	+	+	+				
Dorchester ..	111	+		+	+	+			+	+				
Seale Hayne	693	+	+	+	+	+	+		+	+				

Reliability test of the method.—A standard series of trappings in four standard-type sites was made at Crosby aerodrome (Sta. 56 of Table III) where our field station then was. From intensive field-experimental work over a number of years, 12 species were known to be present in the area. Eleven of these were taken in the test trappings. The exception was *L. richardsi* Collin, of which only three local specimens have so far been identified by us.

Teviothead Station.—During late August 1953, intensive fly-trapping was done in an experimental area on the Roxburgh-Dumfries border (Sta. 57). Some 200 traps were used, sampling a wide range of habitat conditions. The species list obtained is given in Table IV, for comparison with the results obtained elsewhere by the standard method.

The bait.—Ideally, a bait equally attractive to all the species being studied should have been used. Possible alternatives to rabbit were (a) liver, and (b) fish, which might have caught relatively more *Lucilia* (although our experimental evidence on this is rather conflicting), and (c) bait with a chemical added. In order to have the bait of uniform freshness, it was necessary to depend on local supplies, and this ruled out liver and fish for some of the more inaccessible inland stations. Chemical adjuvants to increase the attractiveness of the rabbit for *Lucilia* species would require to be added by the operator, and, in view of the fact that many of the operators had no technical background, uniformity in the bait treatment could not have been guaranteed.

Weather and catch.—A detailed examination of the results in relation to local weather cannot be attempted here, but there were in fact marked differences in the weather conditions during trapping at the different stations, and this was doubtless responsible to some extent for the differences in total catch. A very low catch for one month, for a station which showed reasonably high catches for the other two, obviously reflected bad weather, which was usually confirmed by a note accompanying the catch. Absence of certain species in such low catches is of little significance. Low catches for all three months, on the other hand, probably reflect a low density of carrion-fly population, and the species listed may in such case be a fairly true estimate of the local species pattern.

Repeat trappings.—At Fort Augustus (Sta. 11), the September trapping was omitted on account of continuously impossible weather conditions, and a trapping for this month was arranged for 1954. In four instances the catches were so low in 1953 that the complete series was repeated in 1954. At two stations (Reay Forest and Brecon) repeats for 1954 were initiated but only the June trapping was completed. All stations which include any results for 1954 are marked in Table IV with an asterisk.

Low-catch stations without repeats.—Only two stations require comment in this respect. The result for Sta. 34, near Alston, has been omitted from the Table. Only one *C. erythrocephala* was caught in the June trapping, and only 13 flies (*L. caesar*, *C. erythrocephala* and *C. vomitoria*) in July. Neither the September trapping nor a repeat trapping arranged for 1954 was carried out.

At the other station, Killin (Sta. 18), a 1954 repeat could not be arranged. The station is retained in the Table, however, on account of the interesting capture of *L. ampullacea*.

Interference.—A pleasant feature of the work was the limited amount of human interference with the traps. At one projected station, a country holiday camp, the work had to be abandoned because of persistent interference, but otherwise malicious damage or disturbance was rare. Stock and wild animals proved a bigger source of annoyance, and in several cases traps were opened, probably by dogs or wild carnivores, knocked over by inquisitive stock, or accidentally trampled.

Discussion of probable Distribution.

From the collation of published records of distribution, supported and extended by incidental records, and from the survey results, the distribution of the different carrion-infesting species of the CALLIPHORINAE may now be examined in detail.

Lucilia sericata.

Though *L. sericata* (Mg.) is regarded as very common and generally distributed, the recorded distribution (Table II) shows a surprising number of blanks. Incidental records, mainly of myiasis, confirm the presence of the species in these blank areas, with the exception of Bucks., Stafford and Derby, Isle of Man, Islay and Jura, and Orkney and Shetland. Myiasis is known to occur in Orkney and, more rarely, in Shetland, and in all probability is usually due to this species.

With regard to the "unworked areas" of fig. 1, there are incidental records for Monmouthshire, for all the Welsh vice-counties, and for all the Scottish vice-counties except Renfrew and Dumbarton.

Except in the Home Counties the species, when present in a trap, occurred only in low frequency. The significance of our sporadically distributed failure to take it must therefore be assessed in the light of this observation. In the north, where this relative infrequency in trap catch was most pronounced, the captures were well dispersed, and suggest that the species is generally distributed, but by no means abundant. Its prominence in ecological consciousness is probably a reflection of its economic significance rather than its numbers.

L. caesar.

The recorded distribution of this species reveals relatively few blanks (21) in the worked vice-counties, and these are quite irregularly distributed. Incidental records for the *L. caesar* group, many of them known to have included *L. caesar* (see footnote to Table II), enable seven of the Scottish blanks to be filled in, and also a number of unworked areas. In England and Wales, sheep strike by *L. caesar* and/or *L. illustris* is more infrequent, but this source has nevertheless provided records for two of the blank areas, Herts. and Pems., and for five of the unworked Welsh vice-counties.

With only one exception, Strathspey (Sta. 12), where the high-altitude station captured no *Lucilia* spp., the species was taken at all survey stations, and there is little doubt that it occurs all over Britain.

L. illustris.

The records for this species (*i.e.*, Diptera list records, excluding incidentals), are strikingly fewer than those for *L. caesar*, but the species may be included in or intended by many of the older records of the latter. Scotland has no records, except for one by Grimshaw, queried by the author himself, for the Forth Area (locality unspecified), and one for South Aberdeen. Wales similarly has only four records, one each for Caernarvon, Anglesey, Glamorgan and Skokholm. In England there are large blank areas, notably in the north-west, including the Pennines, and around the Wash and South Yorks. This latter is the more interesting in view of the detailed surveys by White for Lincoln (47), and Hincks for the Spurn Peninsula (3).

The recorded distribution, by vice-counties, is illustrated in fig. 2, areas depending on incidental records being shown by interrupted lines. Included on the map are those survey stations where the species was taken. It will be noted that, apart from the two exceptional stations, Strathspey (high altitude) and Killin (negligible catch), absence in the survey stations is limited to the two



Fig. 2.—The hatched areas show the recorded distribution, by vice-counties, of *L. illustris* and *L. silvarum*. (Interrupted lines for *L. illustris* indicate areas for which there are only myiasis records.) Those survey stations at which one or both species were taken are shown by superimposed square symbols. The single circle represents the Teviothead experimental area (57).

stations in the Western Isles, Glen Etive (Sta. 17) and the Cheviot station, Sourhope (Sta. 30).

The species would thus appear to be almost as generally distributed as *L. caesar*, though possibly less common in hill country and in the north-west.

***L. silvarum*.**

The recorded distribution and the survey results for *L. silvarum* (Mg.) are also shown in fig. 2. It should perhaps be pointed out that the pairing of species in this and the remaining two maps is purely for economy and convenience, and does not imply any special biological association, also, that the absence of a separate symbol for *L. silvarum* for the survey results is merely due to the chance that at no station was the species taken without the paired species.

As shown by the hatching, the published records are confined to England, they are more patchy than the map would suggest, since the inclusion of all Yorkshire is due to a county record, locality unspecified. The only other record for Yorkshire is for the Spurn Peninsula.

The survey results show a very different picture. The vice-county results are confirmed for all stations except Malham Tarn (Sta. 36) and Dorset (Sta. 53), and, for the rest of England, failures occurred only at Lowick (Sta. 31) and Cocker mouth (Sta. 55). In Wales the species was taken at three of the five stations situated in unworked territory, and at two of the remaining three. A typical haunt is shown in Plate X, fig. 3. In Scotland it was taken mainly south of the Highland Line, with four exceptions, Lephinmore, Pitlochry, Fort Augustus and Helmsdale. The scattered distribution of these four would suggest that absence of records of the species, and our failures to take it, are due more to low density in the Highlands than to geographic limitation to its distribution.

***L. ampullacea* and *L. richardsi*.**

The recorded distribution and survey results for these two species are illustrated in fig. 3. For both species the records are almost confined to England, mainly south-east of the Pennines except for a north-west extension from the Midland plain through the Cheshire Gap. With one exception, *L. ampullacea* for Bangor (Cragg & Ramage (9)), there are no records for Wales. The recorded area for *L. richardsi*, embracing Norfolk, Kent and Lancashire, is rather more extensive than that for *L. ampullacea*.

The survey has confirmed the presence of both species in the indicated distribution areas, except for the failure to take *L. richardsi* in Dorset, and *L. ampullacea* in Stratford. Within the known distribution limits, it has added for both species a record for Berkhamsted.

Beyond the mapped limits, *L. richardsi* has been taken in the survey north to Durham and again, surprisingly, on Deeside. It is of interest that it occurred at the Beverley station (Sta. 38), in view of the absence of a record in the detailed Spurn Peninsula survey. Two specimens were taken at Aberystwyth, but at no other Welsh station. Although not taken at the Carlisle station, the species has been trapped on different occasions in the locality in the course of field experimental work.

L. ampullacea, on the other hand, has been found to extend far beyond the mapped limits. In Wales, it was found at all stations except Glamorgan and the high altitude station near Corwen (Sta. 41), where only 28 *Lucilia* altogether were taken in two years' trapping. Northward, it was taken at practically all stations up to the Highland Line, the only notable exception being the group of three in the Merse area, i.e., the Tweed basin (Stas. 27, 30 and 31). Further north, though taken at relatively fewer stations, it occurred at Lephinmore, Killin, Pitlochry, Elgin and Strathpeffer.



Fig. 3.—The recorded distribution of *L. richardsi* and *L. ampullacea*. Interrupted lines (Cumberland) indicate an unpublished record. The survey results are superimposed as square symbols.

It seems that *L. richardsi* is a plains species, and confined principally to the southern part of Britain, whereas *L. ampullacea* is much more widely, and probably generally, distributed. Typical habitats of the two species are shown in Plate X, figs. 2 and 4, respectively.

Phormia terraenovae.

Phormia terraenovae R.-D. is recorded from most of Scotland (worked areas), except Moray, Angus and Lanark, and from England except for Westmorland, the Midland Plain, East Norfolk, and the south coast, for which there are records only for Dorset, Hampshire and Cornwall. It is not recorded from Wales, which is, however, mostly "unworked".

Some of the Scottish vice-counties depend on incidental records of myiasis, as does Cumberland, incidental records being also available for some of the Scottish unworked areas. Since the species does not appear to strike sheep in Wales and southern England, this partly accounts for the greater concentration there of blank areas.

The survey confirms the wide distribution of the species, and partly fills in the main blank areas, *e.g.*, Wales (Stas. 41 and 46), the Midland Plain (Stas. 38, 39 and 48), and the Border Upland (Stas. 29 and 57).

There are numerous blanks in the survey returns, and the numbers caught were always low; this is almost certainly related to the bait used as much as to local distribution and population density level, rabbit flesh being relatively unattractive to the species. Thus, although it was not taken at Berkhamsted (Sta. 50), Mr. L. Stone, of the Cooper Technical Bureau, informs us that it was frequently observed at Little Gaddesden in early summer. Nevertheless, the increasing irregularity of catches from north to south, and the decreasing frequency when present, support the impression gained from the recorded distribution (Table II) that the species is in fact relatively more common in the north.

Calliphora erythrocephala and C. vomitoria.

The distribution of these two species calls for little comment. With a few, almost certainly non-significant exceptions, they are recorded from all the worked vice-counties (see Table II), although in one or two cases, *e.g.*, Herts., Ayr and Lanark, for *C. erythrocephala*, and Mull for *C. vomitoria*, the record is only from an incidental source. There are incidental records also for several of the unworked areas. Both species were taken at all the survey stations except Hereford (Sta. 47).

C. uralensis.

The locality records for this species are extremely few, and the illustrated known distribution (fig. 4) is in this respect misleading, the Hebrides and Arran vice-counties being included by virtue of records from the non-representative localities of St. Kilda and Ailsa Crag. The Inverness hatched area is due to a single record (58) for the Great Glen, locality unspecified. Otherwise the only records are from the north of Sutherland.

It should be remembered, however, that the Diptera lists for north Scotland antedate recognition of both this species and *C. loewi*, and *C. uralensis* particularly would easily have been mis-identified as *C. erythrocephala*.

The survey results, indicated in fig. 4, suggest that the species is in fact restricted to the north-west, all the captures being at stations north of the Great Glen. It is not necessarily a hill-country species, having been taken in the plains of Caithness. A typical habitat is shown in Plate XI, fig. 1.



Fig. 4.—Distribution of *C. uralensis* and *C. loewi*. The single circle represents the Teviothead experimental area (57).

Although not taken at the Skye station it may well be common in the Western Isles.

C. loewi.

This species, though more distinctive than the foregoing species, may also have been included unwittingly in the earlier records of *C. erythrocephala*. Its known distribution (fig. 4) is restricted to north of Perthshire, and, like *C. uralensis*, it is represented by few records.

The survey results show that it is in fact quite widely distributed, and occurs so far south as Malham Tarn. It has occurred in hill stations, *e.g.*, Malham Tarn and the Cairngorms (Sta. 12), and also in fertile plain or lowland ground at Lowick and Carlisle, Edinburgh and Caithness. A typical habitat is shown in Plate XI, fig. 2. It occurred in neither of the two Western Isles stations.

Acrophaga subalpina.

Records for this species are not numerous, and, with the exception of those for three Scottish vice-counties, East Inverness, Moray (Elgin area) and South Perth (Loch Ard), are all grouped irregularly in an area from the Welsh border to Durham, and north of the Severn-Wash line. There is only one record for Wales—Radnor (58).

The survey confirms the Inverness-Elgin records, by captures at Strathpeffer (Sta. 7) and Elgin (Sta. 8), and extends the areas by captures at Fort Augustus (Sta. 11), Pitlochry (Sta. 16) and Aberdeen (Craibstone, Sta. 14). The species was taken at four stations around the Solway basin, a blank region (Stas. 29, 56, 55 and 35), and at two of the three North Wales stations—the hill station near Corwen (Sta. 41) and the lowland station at Welshpool (Sta. 42). For the known English distribution area, its presence was confirmed at Durham, Leeds and the Cheshire Gap (Pl. XI, fig. 3). Failure to confirm the species for the stations at Hereford and Stratford supports the suggestion from the listed distribution in Table II that the species becomes increasingly uncommon southwards, and is rare or absent south of the Severn-Wash line.

Cynomyia mortuorum.

C. mortuorum (L.) is recorded from most of the worked Scottish vice-counties. In northern England there is a large blank area, including Cumberland, Westmorland, the Pennines and West Lancs., and extending through the Cheshire Gap and the west of the Midland Plain to Worcester. Isolated blanks occur in the south, and there are no records of the species for Wales.

The survey results show the species was present at all stations from the far north to the Peak District, with only four exceptions, Reay Forest and Ullapool, Cockermouth and Windermere. It was taken at Leeds and Beverley (Stas. 37, 38), but for the rest of England, south of these stations, occurred at only four stations,—Stratford (Sta. 48), Hereford (Sta. 47), Berkhamsted (Sta. 50) and Compton (Sta. 51). At three of these stations the species occurred as an isolated specimen, and in the fourth as two specimens only, in otherwise heavy catches. In Wales it was taken only at Corwen, and there as a single specimen. A habitat in which disproportionately large numbers were taken is shown in Plate XI, fig. 4.

Other Species.

Protocalliphora sordida (Zett.) occurred, as a single specimen in each case, in the June catches from Ullapool and Glamorgan. Neither *Acrophaga alpina*

(Zett.) nor *Phormia regina* (Mg.) was taken at any station. There is only one record each for these species in Britain, i.e., Glenmore (54), Oxford (44).

Lucilia bufonivora Moniez was taken at Weybridge. It was caught in July in all four traps, totalling 7 ♂♂ and 21 ♀♀ in a catch of 980 *Lucilia* species. It occurred at no other station.

Quite frequently the trap-catch included non-calliphorine material. Sarcophagids were common, and the smaller Muscids and Anthomyiids occurred sometimes in large numbers. Such material could generally be separated at sight from the Calliphorines, and has not so far been further examined by us. Among the material requiring rather closer scrutiny in this preliminary separation we have noted, in passing, occasional Tachinids, Calliphorids (*Pollenia* and *Melinda* spp.), and species of *Muscina*, *Dasyphora* and *Orthellia*.

Notes on Habitat and Seasonal Appearance.

L. richardsi, and to a less extent *L. sericata*, appear to be early-season flies, i.e., they were commoner in the June and July than in the September catches relative to the total blowfly samples. They are flies of open habitat, rarely occurring in shady arenas. *L. ampullacea* tended to be a late-season species. It seems to be obligatorily confined to shady and sheltered conditions, usually associated with woods. *L. caesar*, though to a less marked extent, shows the same habitat preference; *L. illustris* is the most catholic of the group, occurring in all habitat types.

L. silvarum seems to prefer exposed rather than shady habitats, but it is not restricted to them. Seasonally, it tended to occur in the traps more often in June and July than in September, but not to the same marked extent as did *L. richardsi*.

P. terraenovae, also an early-season fly, occurred in all four habitat types, but most frequently in the open exposed type.

C. erythrocephala, and to an even greater extent *C. vomitoria*, haunt sheltered cover. *C. uralensis* and *C. loewi*, though avoiding "exposed and bare" activity arenas, are apparently less dependent on shelter and shade, e.g., woods, than on the field-layer element of "cover". The former species was distinctly more numerous early than late in the season.

Acrophaga subalpina, like *C. vomitoria*, showed a pronounced preference for shelter and shade, whilst *Cynomyia mortuorum* is apparently a fly of exposed habitats. The latter species occurred in more stations in September than in the two earlier trapping months, and was also slightly more frequent in the catches. There was no obvious seasonal effect in the catches of *A. subalpina*.

Typical activity arenas for the less well-known species are illustrated in the photographs.

Summary.

The distribution in Britain of carrion-attracted CALLIPHORINAE was examined by simultaneous trappings, under standard conditions, at 51 stations so distributed as to be more or less representative of the country.

From published records and other sources, the known distribution of each species by vice-counties was delimited and compared with the observed results.

Lucilia sericata (Mg.), *L. caesar* (L.), *Calliphora erythrocephala* (Mg.) and *C. vomitoria* (L.) are generally distributed. *L. illustris* (Mg.) is more widely distributed than was recognised, and is probably general, though relatively uncommon in hill country. *Phormia terraenovae* R.-D. and *Cynomyia mortuorum* (L.) are also general, though more common in the north. The decrease in frequency southwards is more pronounced with *C. mortuorum*, and both species occur only rarely in Wales. *L. silvarum* (Mg.), believed previously to be

confined to England, is also possibly generally distributed; it was trapped as far north as Caithness. It is uncommon north of the Highland Line.

Lucilia ampullacea Villen., for which known records are restricted to south of the Humber-Mersey line, appears similarly to be almost general; it was taken both in hill and plains country up to the Inverness region.

Of the remaining species that show some degree of geographical limitation, *Acrophaga subalpina* (Ringdahl) is the most widely distributed. It occurs at least as far north as the Inverness region, and south to the Severn-Wash line.

The only *Lucilia* species with clearly restricted distribution is *L. richardsi* Collin. Its known territory was England south of the Pennines; this has now been extended into Wales and north to Cumberland and Durham, with one isolated record for the north-east of Scotland.

Calliphora loewi End., believed a northern species, was taken throughout Scotland and northern England. *C. uralensis* Villen. is restricted to the north-west, and the Western Isles.

Brief notes are given of the habitat preferences and seasonal distribution of the species.

Acknowledgements.

The success of a survey of this kind depends very largely on the conscientious co-operation of the field observers, and we would like to express our appreciation of the competent manner in which the operators at all the stations listed played their part. The professional members will understand that no invidious distinction is intended when we say that we owe a special debt of gratitude to those who helped in a private capacity, not only for accepting and executing a responsibility which was for most of them of a totally unfamiliar nature, but also for their loyal adherence to a schedule which must have entailed personal inconvenience in its conflict with the claims of unrelated routine.

Dr. C. D. Day very kindly made available to us details of species and locality records from his private collection.

We have also to thank Mr. W. K. Ford, Keeper of Invertebrate Zoology, City of Liverpool Public Museums, and Mr. C. W. Hunt, Keeper of Biology, City of Leicester Museum and Art Gallery, for volunteering information about the material in the collections under their care, and for permission to publish.

References.

- ELTON, C. S. & MILLER, R. S. (1954). The ecological survey of animal communities: with a practical system of classifying habitats by structural characters.—*J. Ecol.*, **42**, pp. 460–496.
- VAN EMDEN, F. I. (1954). *Diptera cyclorrhapha. Calyptrata* (I). Section (a). Tachinidae and Calliphoridae.—*Handb. Ident. Brit. Ins.*, **10**, pt. 4 (a), 133 pp. London, R. ent. Soc.
- MACLEOD, J. (1943). A survey of British sheep blowflies.—*Bull. ent. Res.*, **34**, pp. 65–88.
- TURRILL, W. B. (1953). *British plant life*.—315 pp. London, Collins.



FIG. 1. The fly trap in use in a site exemplifying the "exposed, bare" category. Note the steady wire loop



FIG. 3. Caernarvon. Typical haunt of *L. silvarum*.



FIG. 2. Hereford. The open type of habitat favoured by *L. richardsi*. The trap was situated inside the Met. Station enclosure.



FIG. 4. Berkhamsted. Thicket habitat of *L. ampullacea*.

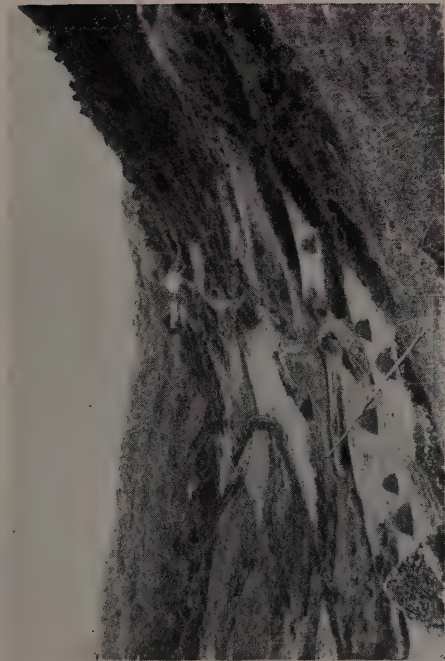


FIG. 1. Crofts in N.-W. Sutherland. An area typical of *C. uralensis*.



FIG. 3. Cheshire Gap station. A wooded hollow, with undergrowth, frequented by *Acrophaga subalpina*.



FIG. 2. Strathpeffer. Numerous *C. loewi* were caught in a trap in the bracken- and whin-covered bank below the tree-line.



FIG. 4. A high corrie (1,600 ft.) in the Southern Uplands. In an experiment in this area, *Cynomyia mortuorum* was taken in disproportionately large numbers.

THE INSECT AND MITE FAUNA OF A SCOTTISH FLOUR MILL.

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From August 1948 until September 1949 a survey of the insect and mite fauna of one of the most northerly flour mills in Britain was carried out. The main object of this survey was an assessment of the occurrence, abundance, distribution and relative importance of the insects and mites present within this flour mill and its associated premises. The faunal list presented here differs from that recorded by Coombs & Freeman (1955) for an empty granary in the south-west of England. As it refers to one mill only, it contains a smaller number of species than that given by Zacher (1938) for German mills, and by Good (1937), who investigated the presence of insects in milling streams of a number of flour mills in the south-west area of the United States.

The flour mill in question was erected about the year 1850, and flour production commenced about five years later. In the year 1888 a serious outbreak of fire in the flour-milling section destroyed most of the machines, which were replaced. The next full-scale replacement of milling machinery took place around 1910. The associated provender mill was installed in the year 1890, and the oatmeal mill in 1904.

The premises surveyed covered not only the flour-milling section but also adjacent grain and flour warehouses, grain-cleaning plant and sack house, as well as provender mill and oatmeal mill. Mill stocks in bags and bulk were subjected to sampling and careful inspection. These stocks ranged from wheat, flour, semolina and offals, to barley and oat products of a similar nature. In addition, a number of already manufactured feeding stuffs such as oil-seed products and fish meal was examined.

Altogether some forty detailed inspections were carried out. Twenty of these were devoted to the flour-milling section, and the remainder divided amongst the other sections under observation. The various sections were classified as either "heated" or "unheated". The former comprised the flour-milling section, the provender and oatmeal mills and the screening section; the latter comprised the grain and flour warehouses and the sack house.

The calendar of surveys was as follows:—

- | | | |
|----------|----------------------|------------------------------------------|
| 1948. | August to September: | Initial survey of flour-milling section. |
| 1948. | October to November: | Initial survey of all other sections. |
| 1948-49. | December to January: | Second survey of flour-milling section. |
| 1949. | February to March: | Second survey of all other sections. |
| 1949. | April to May: | Third survey of flour-milling section. |
| 1949. | August to September: | Fourth survey of flour-milling section. |

The fabric of the buildings and the commodities in store were inspected during production hours, but for a detailed survey of machinery, including worm conveyors, bucket elevators and the like, it was necessary to work when the mill was not in production. Field observations were supplemented by laboratory observations on sieved samples from machines and bags of commodities.

The type of production carried on in a flour mill imposes rather strict limitations on inspections; for example, the movement of mill stocks from one section

* Now in Colonial Research Service in Central Africa.

to another, the inaccessibility of parts of machines as typified by the axis of a centrifugal cylinder, or the space between a hopper and the outside wall of a reduction roll machine. Detailed inspections of chutes were limited to 28 per cent. of the total length present in the flour-milling section. Similarly, only 6 per cent. of the bucket elevator system, and 24 per cent. of the worm conveyor trunking could be examined in detail.

List of Insects and Mites collected.

This particular flour mill yielded a rich fauna of arthropods of which 91 per cent. were insects and 9 per cent. mites. Spiders were not included in this survey. In assessing the numbers of insects and mites present throughout the mill premises, the system outlined by Freeman (1948) was adopted.

The following insect Orders were represented: Lepidoptera (7%); Coleoptera (49%); Diptera (28%); Hymenoptera (5%). The remaining 11 per cent. consisted of individuals of the following orders: Siphonaptera; Hemiptera; Psocoptera; Dermaptera; Thysanura; and Collembola. Not included in this list are unidentifiable individuals of winged Aphids, a Cecidomyiid and a Pteromalid.

LEPIDOPTERA

Representatives of four families were collected:

Caradrinidae

Apamea sordens (Hufn.): one live larva; grain warehouse.

This full-grown larva was taken from bags of home-grown wheat in the month of February. Tams (1949, private communication) states that *A. sordens* normally feeds on grass but retires to wheat stacks during the winter months and emerges in the spring to feed upon grass.

Pyrilidae

Ephestia kuehniella Zell.: all stages; all sections.

In the unheated sections of the flour-mill premises this insect ranged from small numbers to moderate numbers, but in the heated sections large numbers were observed in the summer months. Periodic cleaning of machinery and chutes was necessary to reduce the amount of webbing produced by *Ephestia* larvae.

Oecophoridae

Three representatives of this family were found:

Endrosis sarcitrella (L.): all sections.

Hofmannophila pseudospretella (Stnt.): all sections.

Depressaria applanata (F.): one live adult; grain warehouse.

The last-mentioned on this list of three species is a stray, the larva of which normally feeds on such plants as *Anthriscus*, *Heracleum* and *Angelica*.

Both *E. sarcitrella* and *H. pseudospretella* were well established in the unheated sections but much less well established in the heated sections, and of the two, *Endrosis* had a more tangible hold in the flour-milling section, where up to moderate numbers of larvae were collected in the elevator boots on the ground floor. Adults of both species were taken mostly as single examples in the heated sections, while in the unheated sections the adults ranged from very few to few on most inspections.

In the unheated sections, moderate numbers of larvae of both species were found on the lower half of walls, along floor-wall edges and on window sills, where they appear to overwinter, pupating in the spring.

In heated sections *Endrosis* adults were found throughout the winter, but no *Hofmannophila* adults were taken during this period.

Adults of both species, and to a lesser extent larvae, were collected from empty sacks, imported flour, wheat, grit and animal feeding stuffs.

Tineidae

Tineola bisselliella (Humm.): two live adults were collected from a dead mouse in the flour-milling section.

COLEOPTERA

Coleoptera made up the greater part of the insect fauna of the flour mill. Representatives of 17 families were collected:

Staphylinidae

In all, eight species of Staphylinids were found. These included the following:

Oligota granaria Erichs.: two live adults; sack house.

Proteinus ovalis Steph.: one live adult; grain warehouse.

Oxytelus complanatus Erichs.: one live adult; sack house.

Philonthus fimetarius (Grav.): two live adults; sack house.

Tachyporus hypnorum (F.): one live adult; sack house.

Xylodromus concinnus (Marshall): all sections except oatmeal mill.

Tachinus signatus Grav.: one live adult; flour-milling section.

Atheta sp.: two live adults; flour-milling and wheat-cleaning section.

Adults of *Oligota granaria* were taken, one at each of two inspections, in damp flour spillage on a window sill, and from along floor-wall edges; *Oxytelus complanatus*, *Proteinus ovalis*, and *Tachyporus hypnorum* were found as window specimens; *Tachinus signatus* was collected from a water bucket; and *Atheta* sp. was taken from a wheat elevator boot on one occasion, and from behind a floor-wall fillet on another occasion. Of all Staphylinids listed, adults of *Xylodromus concinnus* were the most common, being collected sometimes singly, and at other times in small numbers from different sites: such as from water buckets in the flour-milling section, and in the unheated sections from bags of wheat and along floor-wall edges.

Tenebrionidae

Seven members of this family were represented:

Gnathocerus cornutus (F.): all stages; flour-milling section.

Tribolium confusum Duv.: all stages; flour-milling section and flour warehouse.

Tribolium castaneum (Hbst.): very few dead adults; sack house.

Blaps mucronata Latr.: single and few adults; flour-milling section and grain warehouse.

Palorus ratzeburgi (Wissm.): one live and one dead adult; wheat-cleaning section.

Tenebrio molitor L.: } very few to few adults and larvae; all sections

Tenebrio obscurus F.: } except sack house.

G. cornutus appeared to favour flour-milling machinery where up to moderate numbers of adults, pupae and larvae were collected. On several occasions the larvae of this species were found amongst webbing produced by larvae of *Endrosis sarcitrella*.

Tribolium confusum was found to be slightly more widely established than *Gnathocerus*. It also appeared to favour the inside of flour-milling machinery where up to fair numbers of adults and larvae were taken.

T. castaneum was collected from empty sacks which had previously contained Paisley meal, and may have been introduced with it.

Adults of *Blaps mucronata* were taken from behind floor-wall fillets and in corners of the ground floor only.

Palorus ratzeburgi was found on empty sacks, once only.

Undisturbed spillage and residues in disused chutes and machinery were characteristic of the habitats of both species of *Tenebrio*.

Cucujidae

The five representatives of this family included:

Laemophloeus ferrugineus (Steph.): } single specimens collected from empty
Laemophloeus turcicus (Grouv.): } sacks in the sack house.
Laemophloeus minutus (Ol.): all stages; flour-milling section and flour
 warehouse.

Oryzaephilus surinamensis (L.): very few live and dead adults; flour-milling section and grain warehouse.

Oryzaephilus mercator (Fauv.): one live adult; sack house.

Laemophloeus minutus occurred in small numbers in the flour warehouse, but reached moderate to fair numbers of adults and larvae locally within the break roll machines, and flour centrifugals in the flour-milling section. *O. surinamensis* was collected from water buckets and elevator boots, and *O. mercator* from damp flour spillage on the ground in the sack house.

Ptinidae

Four species were present:

Ptinus tectus Boield.: few to moderate numbers of adults and larvae; all sections.

Niptus hololeucus (Fald.): very few to few adults; flour-milling section, grain and flour warehouses and provender mill.

Ptinus fur (L.): single and very few adults; sack house, grain warehouse, wheat-cleaning section.

Tipnus unicolor (Pill. & Mitt.): single adults; sack house and grain warehouse.

These Ptinids were collected from the fabric of the buildings and also from chutes and commodities. Association with sacking was common to all of them. They represented an interesting series in their establishment in this flour mill. On the one hand were *Ptinus fur* and *Tipnus unicolor*, sparsely established in unheated sections; on the other hand was *P. tectus*, well established in all sections; and in between was *Niptus hololeucus* with a comfortable hold on both heated and unheated sections, but in numbers appreciably below the level of *P. tectus*. It was noted too that examples of *Niptus hololeucus* were nearly always found close to rat and mouse droppings, on which they are considered to feed. Larval stages of *P. tectus* were found inside mill machinery in the flour-milling section.

Curculionidae

Three species were present:

Calandra granaria (L.): very few to locally fair numbers of adults, both alive and dead; all sections except oatmeal mill.

Calandra oryzae (L.): very few adults, dead and alive; flour-milling section and wheat-cleaning section.

Ceuthorrhynchus contractus (Marsham): one live adult; sack house, collected from one of the windows.

The establishment of the two species of *Calandra* is worth mentioning, *C. oryzae* appeared to be very sparsely established in the flour-milling section and wheat-cleaning section and was not collected from either of the warehouses or from the sack house. *C. granaria* was much more firmly established in the wheat-cleaning section where up to fair numbers of adults were sieved out of wheat screenings and wheat spillage, but elsewhere in the flour mill the establishment of *C. granaria* was only slightly greater than that of *C. oryzae*. Both species

were taken at different inspections from disused chutes, floor-wall edges, empty sacks, and on bags of wheat, maize and barley.

Carabidae

Single adults, all dead, of three members of this family were taken:

Pristonychus terricola (Hbst.)

Calathus fuscipes (Goeze)

Agonum mülleri (Hbst.)

Specimens were collected from along floor-wall edges in the flour-milling section in the case of *P. terricola* and on different floors of the grain warehouse in the case of the other two Carabids.

Cryptophagidae

A single representative, *Cryptophagus cellaris* (Scop.), was collected in larval, pupal and adult stages, and occurred in all sections of the flour mill, particularly in dampish situations such as window ledges, along floor-wall edges, and from amongst damp, mouldy flour or wheat spillage, where up to moderate numbers of larvae and adults were sometimes taken. On one occasion, adults were collected from two of the elevator boots in the flour-milling section.

Lathridiidae

Two species of Lathridiids were found in the adult stage only:

Enicmus minutus (L.)

Coninomus nodifer (Westw.)

Adults were collected singly or in very small numbers from the crevices of the window sills of the flour-milling section and sack house.

Endomychidae

Another family with but a single representative present in the insect fauna of this flour mill:

Mycetaea hirta (Marsham)

Adults were collected (always along with *Cryptophagus cellaris*) either singly or in small numbers from walls or from floor-wall edges in one of the unheated warehouses only.

Anthicidae

Anthicus floralis (L.): one dead adult was collected from a recently painted window shutter in the flour-milling section.

Colydiidae

Aglenus brunneus (Gylh.): single adults were collected from the walls and window sills of the sack house.

Nitidulidae

Epuraea florea Erichs.: one live specimen only was collected from a window in the sack house.

Trogositidae

Tenebroides mauritanicus (L.): very few live adults and larvae were collected from heated and unheated sections of the mill premises, particularly where foci of insect infestation were evident amongst flour spillage, and in elevator boots.

Dermestidae

Dermestes lardarius L.: very few live adults and larvae were collected in the flour-milling section. The larvae were noted burrowing in the wooden floors.

Bostrychidae

Rhizopertha dominica (F.): very few live adults occurred in the wheat-cleaning section and the flour-milling section.

Anobiidae

Anobium punctatum (Deg.): damage by this wood borer was common in the woodwork of the warehouses and particularly in the roof area of the flour-milling section.

Chrysomelidae

Phyllotreta nemorum (L.): one live adult was collected from the lid of a water bucket in the flour-milling section and one dead adult from the sack house.

DIPTERA

Diptera collected in the flour mill come next to the Coleoptera in number, but not in importance. In dealing with the Diptera it is more convenient to classify them according to where they were taken rather than to deal with each family separately. With some exceptions, single adults, alive or dead, were collected throughout the year from two particular sites: (1) from windows and walls, and (2) on bags of commodities. These are dealt with first. This list is followed by one of the Diptera found breeding in flour and grain.

(1) *Specimens collected from windows and walls.*

Chironomidae

Chironomus sp.: flour warehouse and provender mill.

Hydrobaenus sp.: flour warehouse and provender mill.

Metriocnemus sp.: sack house.

Anatopynia varia (F.): grain warehouse.

Scatopsidae

Scatopse notata (L.): flour warehouse, wheat-cleaning house and provender mill.

Mycetophilidae

Sciophila hirta Mg.: wheat-cleaning house.

Sciara sp.: flour warehouse, flour-milling section and provender mill.

Ezechia fusca (Mg.): flour warehouse and provender mill.

Helomyzidae

Tephroclaena oraria Collin: sack house.

Oecothea fenestralis (Fall.): flour-milling section.

Borboridae

Leptocera sp.: flour warehouse, wheat-cleaning section and provender mill.

Paracollinella fontinalis (Fall.): flour warehouse and provender mill.

Drosophilidae

Scaptomyza graminum (Fall.): oatmeal mill.

Agromyzidae

Phytomyza sp.: flour warehouse and provender mill.

Chloropidae

Chloropisca glabra (Mg.): flour-milling section.

Calliphoridae

Calliphora erythrocephala (Mg.): few adults; flour mill, flour warehouse and provender mill.

(2) *Specimens found on bagged commodities.*

Simuliidae

Simulium sp.: on bags of locust beans; sack house.

Muscidae

Fannia canicularis (L.): on bags of Paisley meal.

(3) *Diptera found breeding on flour and grain.*

Anisopodidae

Anisopus sp.: very few larvae collected from amongst wet, fermenting wheat in the wheat-cleaning house.

Psychodidae

Psychoda albipennis Zett.: few adults in flight in oatmeal mill and wheat-cleaning house.

Psychoda severini Tonnoir: a few larvae and pupae of this species and of *P. albipennis* were collected from amongst wet, fermenting grain in the wheat-cleaning house.

Scatopsidae

Scatopse sp.: very few larvae collected from amongst damp grain-dust along floor-wall edge of sack house. (One specimen retained by British Museum for their collection.)

Mycetophilidae

Sciara sp.: one larva collected from undisturbed dust accumulations along floor-wall edge in the flour warehouse and sack house.

Drosophilidae

Drosophila funebris (F.): flour-milling section.

D. funebris deserves special mention as the only species of Diptera taken from mill machinery in the flour-milling section: a few adults were found within the second and third break roll machines, and from the latter a few larvae were taken on two occasions. These were from amongst rotten flour within the machine. Adults were also collected from associated bucket elevator boots.

This species appears to breed well in fermented grain and grain products. The author has collected both larvae and pupae of this species from rotten grain on several occasions in grain silos in Northern Ireland.

HYMENOPTERA

Hymenoptera were quite rare in this flour mill; in all, only very few individuals were taken throughout the year. With the exception of *Lariophagus distinguendus* (Foerst.) these were collected as dead adults from windows. The absence of *Nemeritis canescens* (Grav.) and *Bracon hebetor* Say, both parasites of the larval stage of *Ephestia kuehniella*, is noted in this flour mill.

Braconidae

Blacus sp.: flour-milling section.

Ichneumonidae

Pimpla melanacrias Perkins: flour-milling section.

Pteromalidae

Lariophagus distinguendus (Foerst.): this species is a parasite of *Calandra* spp.: a very few adults were collected alive near the wheat-elevator boot in the flour-milling section; in addition, three dead adults were sieved from wheat screenings in the wheat-cleaning section.

Proctotrupidae

Exallonyx longicornis (Nees): sack house.

SIPHONAPTERA

This Order was represented by one species, *Nosopsyllus fasciatus* (Bosc), collected as single live adults on several occasions in the flour-milling section, the flour and grain warehouse and the provender mill.

HEMIPTERA

Like the previous Order, only one representative (apart from unidentified winged Aphids) was collected: *Lyctocoris campestris* (F.). This predacious Anthocorid was taken, both alive and dead, mostly as single adults, in the flour-milling section, the oatmeal mill, the flour and grain warehouses and the provender mill.

PSOCOPTERA

This Order was represented by two species:

Lepinotus patruelis Pearman

Trogium pulsatorium (L.)

These two species occurred together from few to large numbers in the flour and grain warehouses, particularly on grain-dust drenched walls and wooden partitions separating bulk grain. They also occurred in lesser numbers in the other sections, heated ones as well as unheated. Some of the Psocids were found inhabiting holes made by *Anobium punctatum*.

DERMAPTERA

Only two live specimens (one male and one female) of *Forficula auricularia* L. were taken on introduced empty sacks in the flour-milling section.

THYSANURA

Lepisma saccharina L. was found in the sack house, a very few live individuals being collected from along floor-wall edges amongst undisturbed accumulations of dust.

COLLEMBOLA

This Order was represented by two species:

Mydonius nivalis (L.): one live adult; sack house.

Mydonius marginatus (Tullberg): few live adults; flour-milling section.

M. nivalis was collected from a corner of the sack house along with *Cryptophagus cellaris*. Members of the other species were found inhabiting a ceiling of the flour-milling section, behind the flaked limewash, where they quickly hid when disturbed.

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Mites were a regular feature of collections made within the flour-milling section and the grain and flour warehouses as well as the oatmeal mill and the scouring house of the wheat-cleaning section. All stages of *Tyroglyphus farinae* (Deg.) were collected. This mite was by far the most common and economically important of those present. In damp situations up to large numbers were noted amongst flour and other cereal debris. In lesser numbers, and mostly in the adult state, *Glycyphagus destructor* (Schr.), *Tydeus interruptus* Thor, *Cheyletus cruditus* (Schr.) and *Gohieria fusca* (Oudm.) were taken from floor-wall edges, and in floor cracks. Single specimens or at most only very few individuals of *Haemogamasus oudemansi* Hirst, *Macrocheles muscae-domesticae* (Scop.) and *Parasitus* sp. were collected in the neighbourhood of the wheat-elevator boots on the ground floor of the flour-milling section.

Discussion.

Altogether 85 species of insects and eight species of mites were taken during the course of inspections in this flour mill and all its associated buildings. Of the arthropods listed, about one quarter were considered to have a limited economic significance as pests, while three species appeared to be almost wholly responsible for interference with the milling processes and contamination of the finished products. These three important pests were *Ephestia kuehniella*, *Gnathocerus cornutus* and *Tribolium confusum*. During inspections of the flour-milling section, these pests were collected in greater numbers from floors above ground level than at ground level, where temperatures were lower and more comparable with those in unheated sections. These records of increasing numbers on the upper floors may be contrasted with records of other species taken in an unheated building (Coombs & Freeman, 1955) where, in general, the numbers of insects increased on descending the warehouse. It is interesting to notice that none of the three species that were found, in the present work, to be important, was recorded at all by Coombs & Freeman. In the rather different habitats examined by them, the dominant species were *C. granaria* and *H. pseudospretella*.

G. cornutus and *T. confusum* both inhabited milling machinery where temperatures were higher than elsewhere in the flour-milling section. These two species are considered by Solomon & Adamson (1955) to be, respectively, very susceptible and moderately susceptible to low-temperature conditions such as normally exist during winter in Britain. This may explain their failure to become established in the unheated sections of this flour mill, and their absence from the empty granary studied by Coombs & Freeman.

Ephestia kuehniella, however, has been found capable of withstanding winter conditions and this appears to be confirmed by its ready establishment in the unheated sections of this flour mill. The same is true of the Ptinids collected as well as of both species of *Tenebrio*, all of which are placed in the "hardy" group of insects by Solomon & Adamson. From observations carried out in the unheated sections of this mill it would appear that *Endrosis sarcitrella*, *Tipnus unicolor* and *Cryptophagus cellaris* might safely be included in the list of "hardy" insects, able to survive the winter in unheated buildings. This is in agreement with the results obtained by O'Farrell & Butler (1948) (as quoted by Solomon & Adamson (1955), who did not study these species). It is suspected that both *E. sarcitrella* and *T. unicolor* overwinter in larval form whilst *C. cellaris* may do so in either adult or larval form.

Pests of secondary importance in this particular flour mill included *Calandra granaria*, *Tyroglyphus farinae*, *Laemophloeus minutus*, *Hofmannophila pseudospretella*, *Endrosis sarcitrella* and *Ptinus tectus*. Both *E. sarcitrella* and *P. tectus* appeared to increase more rapidly if allowed undisturbed living conditions. The remainder of the fauna contained many stored-products species which occurred in such small numbers as to form only a relatively small proportion of the mill population, with consequently little or no pest value.

In addition, the fauna included mould feeders such as the Cryptophagids and Lathridiids, strays (most of the Diptera and others), parasites (representatives of the Orders Hymenoptera and Siphonaptera) and predators which consisted of Staphylinids and some of the mites.

Summary.

Insects and mites collected within the various sections of a combined flour, oatmeal and provender mill are listed. The mill in question is one of the most northerly in Britain. Notes are given on the distribution, abundance and associations, within the mill, of the species recorded. The economic importance of those considered to be pests is assessed.

The three most important pests were found to be *Ephestia kuehniella* Zell., *Gnathocerus cornutus* (F.) and *Tribolium confusum* Duv. It is suggested that *Endrosis sarcitrella* (L.), *Tipnus unicolor* (Pill. & Mitt.) and *Cryptophagus cellaris* (Scop.) might be included in the list of "hardy" insects given by Solomon & Adamson (1955) in their paper on the powers of survival of storage and domestic pests under winter conditions in Britain.

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References.

- COOMBS, C. W. & FREEMAN, J. A. (1955). The insect fauna of an empty granary.—Bull. ent. Res., **46**, pp. 399–417.
- FREEMAN, J. A. (1948). World foci of infestation and principal channels of dissemination to other points, with suggestions for detection and standards of inspection. In Easter, S. S. *Ed.* Preservation of grains in storage.—FAO agric. Stud., no. 2, pp. 15–34.
- GOOD, N. E. (1937). Insects found in the milling streams of flour mills in the southwestern milling area.—J. Kans. ent. Soc., **10**, pp. 135–148.
- O'FARRELL, A. F. & BUTLER, P. M. (1948). Insects and mites associated with the storage and manufacture of foodstuffs in Northern Ireland.—Econ. Proc. R. Dublin Soc., **3**, pp. 343–407.
- SOLOMON, M. E. & ADAMSON, B. E. (1955). The powers of survival of storage and domestic pests under winter conditions in Britain.—Bull. ent. Res., **46**, pp. 311–355.
- ZACHER, F. (1938). Die Gliedertiere (Arthropoda) der Mühlen und Getreidespeicher in Deutschland. 4. Beitrag zur Kenntnis der Mühlen- und Speicherbiozönose.—Mitt. Ges. Vorratsschutz, **14**, Sonderheft, 48 pp.

AIRCRAFT APPLICATIONS OF INSECTICIDES IN EAST AFRICA.

XI.—APPLICATIONS OF A COARSE AEROSOL TO CONTROL *GLOSSINA MORSITANS* WESTW. AT URAMBO, TANGANYIKA, AND *G. MORSITANS* WESTW. AND *G. PALLIDIPES* AUST. IN LANGO COUNTY, UGANDA.

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Previous papers in this series have described experiments that investigated the possibilities of using aircraft applications of insecticides to control tsetse flies (*Glossina* spp.) in East Africa. It has been shown (Hocking & Yeo, 1953) that aircraft applications would almost certainly be prohibitively expensive for the effective control of *Glossina palpalis* (R.-D.), the species associated with dense riverine vegetation; significant kills were obtained using coarse aerosols with mass median diameters of approximately 90 microns, but the reductions in fly populations were not big enough to be of practical value; and coarse sprays, with mass median diameters of 700 microns, produced no significant kills. Experiments in savannah woodland (Hocking, Parr & others, 1953*a*, 1953*b*) showed again that the coarse aerosols were more effective than coarse sprays, and very high kills were obtained when they were used against populations of *Glossina morsitans* Westw. and *Glossina swynnertoni* Aust. In a later experiment (Hocking, Yeo & Anstey, 1954) very large reductions were again obtained in populations of *G. morsitans* and *G. swynnertoni*, and *Glossina pallidipes* Aust. was eradicated; and in another experiment (Hocking, Burnett & Sell, 1954*a*) *G. swynnertoni* was probably eradicated. A further paper (Hocking, Burnett & Sell, 1954*b*) described a less successful attempt to use aircraft during the rainy season.

As a programme of field research these experiments formed a complete series, and it was felt that more fundamental studies were necessary before any notable advance in techniques and economy could be achieved. They were, however, artificial in that great efforts were made to choose experimental areas where the results would not be complicated by too many uncontrolled field variables, and there was usually a larger staff of Europeans and Africans than would be acceptable for routine control. When, therefore, two problems in tsetse control were presented for which aircraft applications of insecticide might be used, it was considered worth-while to take advantage of the presence of trained staff and suitably fitted aircraft and to carry out what were in effect pilot schemes with this method of tsetse control. The scheme at Urambo, Tanganyika, was a failure, mainly because it was impossible to prevent re-infestation of the treated areas from nearby fly-infested woodland; this scheme also showed in a striking fashion some of the inherent difficulties and disadvantages of controlling tsetse flies with insecticides applied from aircraft. The other scheme, which was carried out in Lango County, Uganda, was highly successful and illustrated what can be achieved in suitable circumstances.

The Control of Dosage, and Field Methods.

The principles of the technique of application have been described elsewhere (see for example Hocking, Yeo & Anstey, 1954). Oil solutions, containing either DDT or BHC, are applied as coarse aerosols which in the later work have had mass

median diameters of approximately 60 microns. The applications are carried out so that each section of woodland is treated at intervals of approximately two weeks, and they are continued until the series covers a period rather longer than two average pupal periods. Successive sorties upon adjacent sections of woodland are overlapped to prevent the escape, by movement between sorties, of an appreciable number of flies. The aircraft is flown as close as possible to the top of the canopy.

In both experiments described in this paper, as in most of our previous work, each application was made at a nominal dosage of 0.25 gallons of solution per acre. At Urambo both DDT and BHC were applied, using oil solutions which contained either 10 per cent. w/v of technical DDT (80 per cent. p,p' isomer) or 5 per cent. w/v of S.G. 215 (26 per cent. γ isomer of BHC), whereas in Lango County only DDT was used, made up into an 11 per cent. w/v solution of technical DDT (75 per cent. p,p' isomer). In both experiments the solvent consisted of equal parts by volume of Shell Power Kerosene and Shell Diesoline. At nominal dosages of 0.25 gallons per acre these figures correspond to nominal dosages of either 0.20 lb. of p,p' DDT, or 0.03 lb. of γ BHC, per acre; unpublished laboratory work had shown that the two insecticides were equally effective at these comparative dosages. At Urambo, swathe widths of 70 yd., and overlaps of 400–500 yd.,

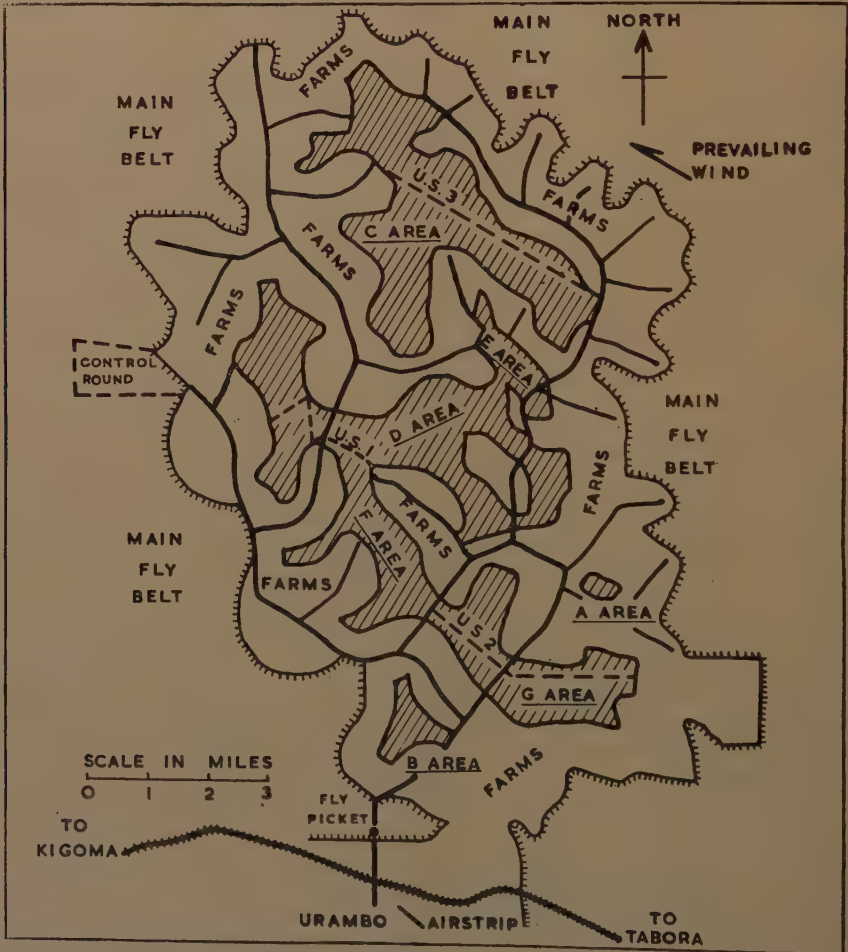


Fig. 1.—A map of the experimental area at Urambo, Tanganyika.

were used. In Lango County the swathe widths were reduced to 55 yd., partly because it was felt that flying errors might be more important with the greater width of the experimental area, and also because it was felt that the dense thickets in parts of the area would reduce the effective swathe; the overlap was approximately 250 yd. wide. The original intentions were to have an interval of 16–17 days between applications at Urambo, and 15 days between those in Lango County, an unimportant difference according to unpublished calculations by Burnett.

The Experiment at Urambo, Tanganyika.

Urambo (lat. 05°04'S. long. 32°05'E.) is approximately 3,600 ft. above sea level, and lies within the extensive belt of "miombo" woodland that covers much of western Tanganyika. The upper canopy included trees of *Brachystegia boehmii*, *B. spicaeformis*, *B. wangermeeana*, and *B. longifolia*, and there were many other species; there was also a light understorey of smaller trees, including *Combretum* spp., *Ostryoderris* sp., and *Terminalia* spp. The area was chosen for development by the Overseas Food Corporation, and extensive clearings had been made and farms had been laid out. The woodland was infested by *G. morsitans*, and since in general only the higher ground had been cleared, leaving untouched the less fertile wooded land of the drainage lines, the farming land was interspersed with fly-infested woodland to such an extent that it was not considered possible to keep livestock. In one of the main farming units some sheer clearing of drainage lines had isolated, at least partially, the woodland within the farms from the main fly-belt, and this unit, shown in fig. 1, was chosen for the experiment.

It was hoped that the populations of *G. morsitans* in these isolated woodlands (designated, for the purpose of the experiment, areas A to G (see fig. 1)) would be eliminated or greatly reduced, so that livestock could be kept with little risk of trypanosomiasis. The insecticidal applications were made with DDT in all such woodland except area C, where BHC was used.

The population density of *G. morsitans* varied very considerably. In the main fly-belt to the west and south of the farming unit the apparent density, i.e., the number of non-teneral male flies caught per 10,000 yd. of fly-path (Swynnerton, 1936), varied from 100 to 250; outside the northern edge of the unit it was approximately 100, whereas outside the eastern and north-eastern edges it was only 10–20. Before the applications were started, apparent densities of 200 and more were recorded in area G; in areas D and C they were respectively 60 and 25.

It may be seen from fig. 1 that in many places the treated blocks were separated from the main woodland by clearings that were only 800–1,000 yd. wide. Before the applications were started, the Overseas Food Corporation agreed to clear certain woodland so that at no point would the main belt be less than one mile from the treated blocks. Unfortunately a very rigid system of economy was imposed at Urambo just as the experiment was started and money was not available to complete such clearing work, with the result that in several places heavily infested woodland was dangerously near to the treated areas.

Approximately 24 square miles of woodland were treated. The first application started on 13th August 1952, and the last sortie was made on the 16th November 1952. Based upon the assumption that the meteorological conditions would be suitable for one sortie in the early morning, and that sorties would occasionally be possible in the late evening, it was estimated that a complete application would take 14–16 days with the two Avro Anson aircraft. Also, as it was decided that the interval between applications in any section of woodland should be 16–17 days, this allowed some margin for abortive sorties. Using a formula given by Jackson (1949), the average temperatures before the applications were started indicated that pupal periods for females were of the order of 30–40 days.

It was therefore decided to carry out six applications, covering a period of 80-85 days, or rather more than two pupal periods. However, owing to a series of accidents to the aircraft, luckily without injury to the air-crews, only the first four applications were carried out at approximately the required intervals; in area G, a most important focus of flies, the fifth application was so delayed that the interval there between the fourth and fifth applications was extended to 20-26 days. The sixth application was also seriously delayed, and was not completed except in areas A, C, D and E, because by then both aircraft had been seriously damaged. In the event, therefore, two pupal periods were not satisfactorily covered by the applications, particularly where there were high population densities.

Entomological results.

Three fly-paths (U.S. 1-3) were laid out in the treated woodland (see fig. 1) and there was a control round in the main fly-belt. Between applications, searches in each section were made as soon as possible after treatment, and again after a further interval of one week, and sometimes there was also a search immediately before an application. The catches are summarised in Table I.

TABLE I.

Catches of *G. morsitans* at Urambo.

Fly-path	DDT Areas				BHC Area		Control	
	U.S. 1		U.S. 2		U.S. 3		Non- teneral males	All flies
	Non- teneral males	All flies	Non- teneral males	All flies	Non- teneral males	All flies	Non- teneral males	All flies
July 1952 ..	32	39	192	220	25	35	82	101
Aug. ..	30	38	100	114	29	44	47	62
13th Aug. —	FIRST APPLICATION							
	11	14	11	16	1	1	71	87
	5	12	25	38	4	6	36	58
	SECOND APPLICATION							
	0	1	0	2	0	5	43	61
	8	14	2	10	1	1	59	83
	6	12	21	36	—	—	38	51
	THIRD APPLICATION							
	0	0	0	0	0	0	49	65
	0	0	1	2	2	5	57	71
	5	6	0	0	0	0	—	—
	FOURTH APPLICATION							
	2	8	0	1	—	—	64	95
	0	1	0	0	1	1	—	—
	FIFTH APPLICATION							
	0	0	0	0	0	0	—	—
—16th Nov. —	SIXTH APPLICATION							
Nov. ..	1.5	2	2	3	0	0	23	64
Dec. ..	3	5	3	7	2	3	56	133
Jan. 1953 ..	7	11	9	10	4	6	75	123
Feb. ..	4.5	6.5	8	12.5	10	15	—	—
Mar. ..	7.0	9.2	16	20	16	21	—	—
Apr. ..	8.8	12	22	26	17	20	79	135
May ..	16	20	26	32	22	26	83	121
June ..	13	19	13	18	20	28	47	76
July ..	10	15	10	14	9.8	15.5	43	65
Aug. ..	9.6	13	6.5	9.5	5.2	9.5	33	52
Sept. ..	25	31	15	17	9.5	16.0	37	51
Oct. ..	14	21	12	16	9.5	12.5	21	36
Nov. ..	17	28	23	46	13	21	13	27
Dec. ..	27	39	56	64	12.5	17	24	32
Jan. 1954 ..	40	56	44	52	55	70	44	55
Feb. ..	41	65	53	81	60	83	29	40
Mar. ..	45	55	66	71	81	109	32	36
Apr. ..	44	59	35.5	45	78	88	27	32
May ..	44	56	40	53	110	120	42	54
June ..	21	28	17.5	20	54	70	47	79
July ..	18.5	22	11.7	15	45	55	15.5	21.5
Aug. ..	8.0	12.5	9.0	14.3	16.5	20.5	15.5	21.2
Sept. ..	7.3	10.7	6.5	9.0	18.7	21.7	5.5	9.2

They show that the population had fallen to a very low level by the fifth application, but at no time was there a very long period in any area when no fly was caught.

During August 1952 the catch of non-teneral males averaged 159 for a complete search of the three fly-rounds. After the first application a complete search gave 23 non-teneral males, suggesting that the kill per application was about 85 per cent. Considering the figures for August 1952 and December 1952, and correcting for variations in the control, catches of non-teneral males suggest an average reduction of 95 per cent., which is high but not as high as in most of our other experiments.

During the experiment it became evident that movement of vehicles and people in and out of the area was very considerable. Many of the roads along the western part of the unit were closed, but unfortunately one road, leading from the main fly-belt through the woodland containing the fly-path U.S. 1 (see fig. 1), was used extensively during the early applications and was not effectively closed until the end of the fourth application, and the catches prior to this suggest that in this section the treatment was apparently least effective. A fly-picket was maintained on the main highway leading southwards from the farming unit, and each week 100–300 flies were collected there; most of these were probably picked up by travellers moving through the main fly-belt near the picket, but this must surely mean that many flies were also carried northwards into the experimental area. It may be seen in fig. 1 that in many places the clearings between the main belt and the treated woodlands were only about 800 yd. wide; this would be considered a narrow clearing where movement of people was slight, and was certainly too narrow in this case where movement of flies with people and vehicles was very considerable. It is almost certain, therefore, that flies moved into the treated areas from the surrounding woodland.

The data in Table I show some very large seasonal fluctuations in catches; they also show that the variations in the control did not correspond very closely to variations in the three treated areas covered by fly-paths, although in August

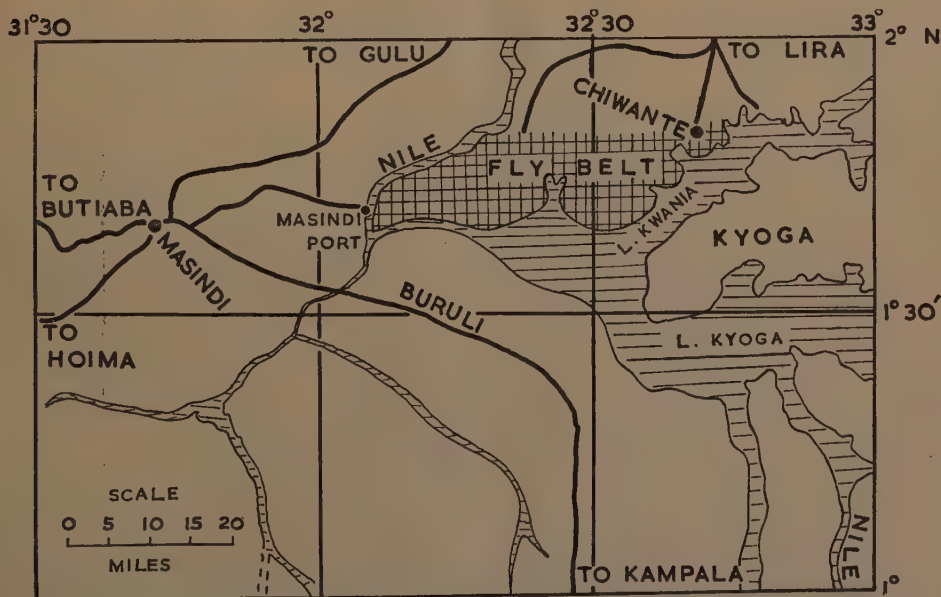


Fig. 2.—A map showing the general situation of the fly-belt in Lango County, Uganda.

and September 1954 all catches showed a marked decrease. In March, April and May 1954, the catches on the three fly-paths taken together were as high as they were in August 1952, just before the applications started, and although this may have represented an abnormally high peak there seems to be little doubt that by then the populations had in general recovered to a considerable degree from the drastic reduction produced by the treatment. This is our only experiment against tsetse flies living in savannah woodland where such a recovery has taken place, but it is also the only experiment where the immigration of flies on a considerable scale almost certainly occurred.

The Experiment in Lango County, Uganda.

The situation in Lango County, Uganda, was a most interesting special case of the tsetse problem in East Africa. A map (fig. 2) is given which shows that the infested area was a relatively narrow belt of woodland extending eastwards

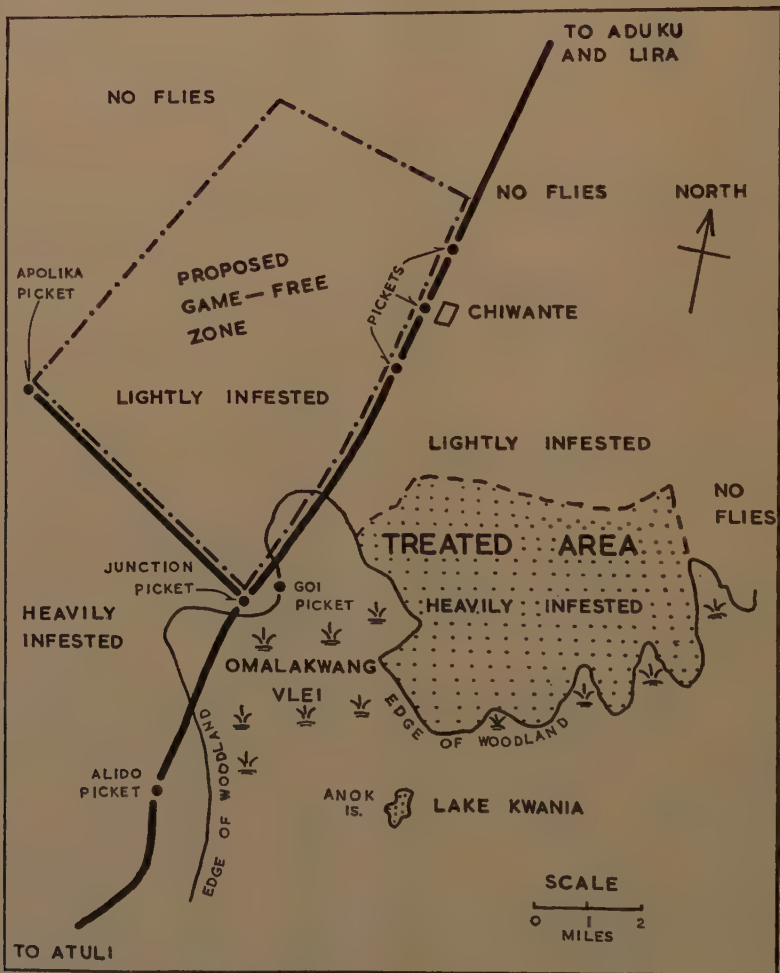


Fig. 3.—A map of the Chiwante area, Uganda, showing the distribution of tsetse flies, the treated area, and the precautions taken to prevent re-infestation by immigrant flies.

from Masindi Port along the northern shore of Lake Kwania. Intrinsically the fly-belt was of no great economic importance; with its poor soil it was unattractive to settlers, and there was no land shortage in this part of Uganda. There was a very real danger, however, that the infestation would spread into Kyoga, where large numbers of livestock are kept, and there was also a danger that flies would re-infest the reclaimed land south of Lake Kwania; furthermore, both of these threatened areas are close to important trade routes for livestock.

It had been shown that aircraft applications of insecticide could rapidly reduce a fly population to a very low level, and it seemed likely that they would be well suited to this problem of removing a threat to important settled areas. Preliminary surveys late in 1952 indicated that the country was mostly undulating land covered with light combretaceous woodland, and that it had few topographical features that would greatly interfere with the flying. It was considered that although the patches of thicket, which were important foci of fly concentrations, might decrease the effectiveness of the aerosol by shielding flies, insecticidal applications would nevertheless drastically reduce the fly populations. The surveys also showed that the main fly-belt was so big that it would have been unwise to consider treatment of the entire fly-infested woodland without first carrying out a pilot scheme. South of Chiwante (lat. $01^{\circ}50'N.$, long. $32^{\circ}42'E.$), a relatively open area was seen where a good barrier could be made to isolate the eastern end of the fly-belt, and it was decided that the fly-infested woodland to the east of this open area should be treated in a preliminary experiment.

An approximate map of the Chiwante district is given in fig. 3. The experimental area is east of the road from Alido to Chiwante. Two species of tsetse, *G. morsitans* and *G. pallidipes*, were known to be present. Early searches,

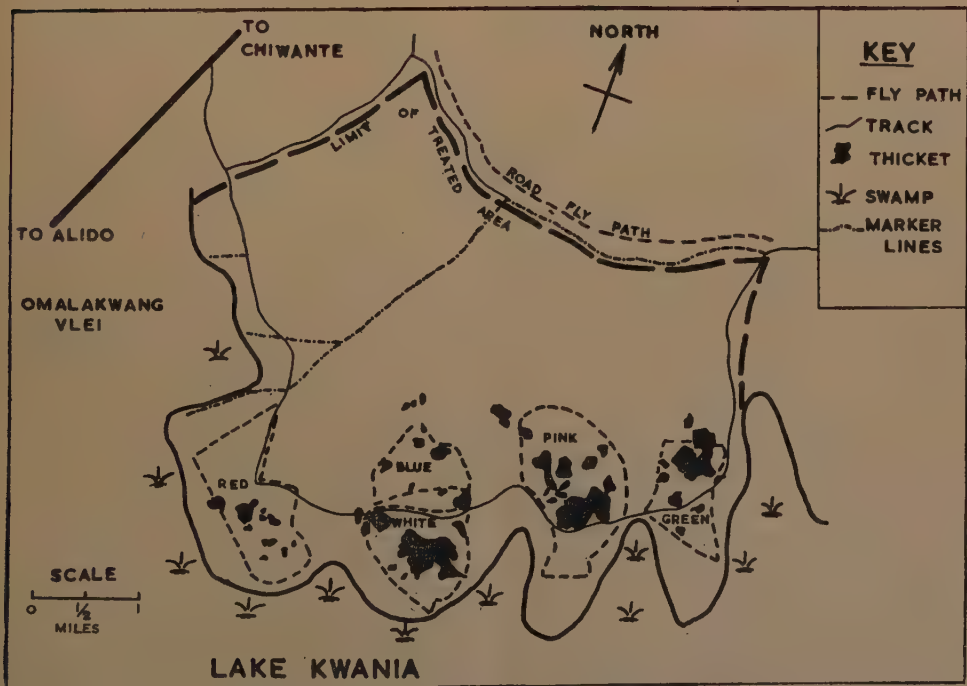


Fig. 4.—A map of the treated area at Chiwante, Uganda.

carried out by the Uganda Tsetse Control Department, showed that there were relatively few *G. pallidipes* and that they were only to be found in the areas containing thicket near the shores of Lake Kwania; the numbers of *G. morsitans* were also greatest near the lake, and fell off rapidly towards the north. This picture was confirmed by more intensive searches in January 1953, which also showed that although tsetse flies could be found in 40 square miles of woodland to the east of the main road, the main concentrations were in fact confined to about 15 square miles bordering the northern shore of Lake Kwania. The rest of the experimental area contained very few flies, which were possibly wanderers from the fly concentrations. It seemed rational, therefore, to deal with the fly concentrations first, at the same time keeping a check upon fly numbers in the lightly-infested woodland to see if it would in fact be necessary to treat the entire 40 square miles.

A map of the treated area is given in fig. 4, which shows the main thickets, fly-paths, and the marker paths used for indicating the positions of the runs to the pilots. Approximately 16 square miles of woodland were treated. The first application started early in March 1953, and mainly because of bad weather, but also because one of the pilots was called up for emergency duties in Kenya, only seven complete applications were made, at intervals of 15–18 days for any particular section of woodland. The eighth application, which was finished early in July 1954, covered only those parts that had originally supported the higher fly populations.

The Urambo experiment had clearly shown that for success it was vital to isolate the experimental area from other fly-infested woodland. As may be seen from fig. 3, re-infestation was only possible from the west and north-west; the woodland to the east and north was not infested, and the shore of Lake Kwania formed the southern boundary. North of the Omalakwang vlei (an open swampy area) there was a light infestation, and to stop any eastward movement of these flies, pickets relying upon hand-catches were established on the more important paths crossing the main road near Chiwante. A more serious cause of infiltration was likely to be flies carried by cyclists and pedestrians moving along the main road towards Chiwante, and along a track crossing the Omalakwang vlei. Further pickets were therefore established at strategic points along the roads. Catches at the various pickets are summarised in Table II, which also records the numbers of people who passed the pickets, and they show that each month several hundred flies were being carried towards the experimental area. The pickets could not cover all possible channels of movement, and to reduce the chances of immigration it was proposed to make a game-free zone, approximately seven miles long and five miles wide, along the western boundary of the experimental area; this zone was to be fenced and all game within it was to be shot; by leaving only specified gaps in the fences, it was also hoped that all humans would have to pass through one or other of the pickets. In the event, the fences were not erected until September 1953, two months after the applications had stopped, and were removed in June 1954, and the shooting of game was never completed.

A picket that relies upon hand-catching is never completely effective, and is in fact exceptional if it catches 90 per cent. of the flies that are brought to it, so that the figures given in Table II indicate that each month several score of flies were reaching the north-western edge of the experimental area. As will be seen later, these flies did not re-establish any effective population in the experimental area, at any rate not for the year following the treatment, from which it must be inferred that the woodland north of the treated area and east of the main road must have been inhospitable to flies and therefore formed an effective barrier. This does not imply that the precautions were wasted; the greater degree of infiltration that would have existed without the pickets might well have caused serious re-infestation.

TABLE II.

The numbers of flies (*G. morsitans* and a few *G. pallidipes*) obtained by hand-catching at the various pickets. The Table also records the numbers of pedestrians and cyclists passing each picket.

Month	Chiwante pickets		Goi picket				Road junction picket						Aldo picket				Apolika picket			
	from west		from west		from east		from north		from west		from south		from north		from south		from west		from east	
	P*	F†	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F
Feb. 1953	—	—	983	5	1080	17	1137	71	1050	190	1053	123	—	—	—	—	—	—	—	—
Mar.	2393	230	1026	6	1069	11	1568	19	1525	166	1382	84	—	—	—	—	—	—	—	—
Apr.	2802	84	713	8	834	0	816	3	1077	52	1414	37	—	—	—	—	—	—	—	—
May	2332	61	701	10	561	0	1643	0	1487	123	1792	103	—	—	—	—	—	—	—	—
June	2022	96	280	3	—	0	1510	0	1341	123	1722	108	—	—	—	—	—	—	—	—
July	2173	35	80	3	—	0	1475	6	1252	103	1472	68	—	—	—	—	317	86	373	46
Aug.	1688	44	69	1	96	1	1506	15	1241	123	1326	52	654	12	711	221	708	142	678	101
Sept.	1728	57	57	0	84	0	1351	14	1352	236	1452	152	259	32	438	208	815	142	770	282
Oct.	1581	45	135	3	51	0	1484	13	1403	271	1467	166	570	128	547	414	758	298	577	232
Nov.	1272	38	47	3	60	0	1377	9	1422	174	1536	96	537	70	654	303	515	152	537	152

P* = Number of pedestrians and cyclists passing the picket.

F† = Number of flies caught at the picket.

Entomological results.

In February 1953, fly-paths were established where there were high population densities of flies. In the northern parts of the treated area, and also in the lightly infested woodland further north, it was not considered worthwhile to have many regular fly-paths, but one path was established along a track bordering the northern limit of the treated area, and frequent random searches were also made. Up to the middle of June 1953, catches were made by two assistants using screens; such a technique, although adequate for *G. morsitans*, was not ideal for *G. pallidipes*, and so, from the middle of June, searches were made with bait cattle, the most effective method of catching *G. pallidipes* and one that is suitable for *G. morsitans*.

During February and March 1953, before the applications started, searches totalling 170 miles were made, and 1,800 *G. morsitans* and 2 *G. pallidipes* were caught. The apparent density of *G. morsitans* was 10 in the western part of the treated woodland, 140 in the central section covered by the White and Blue Paths (see fig. 4) and 5 in the eastern parts; in the rest of the area the apparent density was generally less than 1. Assuming that an apparent density of 1 is equivalent to a population of 7 male flies per square mile (see Jackson, 1949), and that there are twice as many females as males, both of which are reasonable assumptions, it was estimated that the total population was initially of the order of 10,000 flies.

Before treatment, the average catch of non-teneral males was 166 for one complete search of the five main fly-paths; immediately (1-3 days) after the first application, four non-teneral males were caught, indicating a kill for this application of about 98 per cent. Apparently the second application did not achieve such a high kill, but the series as a whole was most effective, as may be seen from Table III, which records the average catch of all flies. The Table considers all flies rather than only non-teneral males because after the treatment the numbers caught were few, and also because any fly caught then was of importance. The catches may be summarised by saying that before the treatment a complete search on the five fly-paths, which totalled 19 miles, gave 193 flies, whereas 2,400 miles of search, using bait cattle over a period of one year following the seventh application, yielded no *G. pallidipes* and only 14 non-teneral *G. morsitans*; this corresponds to a reduction of over 99.95 per cent. The variations in the control catches at Atuli, some ten miles to the south-west of the treated area, suggested that there were no very large or abnormal changes in populations in untreated areas.

Discussion.

It is considered that the attempted control at Urambo failed because it was impossible to stop the considerable movement of flies into the treated areas. In reclamation work by the East African Tsetse and Trypanosomiasis Research and Reclamation Organisation, a sheer clearing one mile wide is used where there is little movement of pedestrians and vehicles across it, and even so pickets are also established. At Urambo there were stretches where the clearings between the treated woodland and the main fly-belt were only 880 yd. wide, so that a certain amount of immigration might have been expected in any case; Swynnerton (1936) and Burnett (1954) give some details for movement of *G. swynnertoni*, a similar species, across clearings, and when this is supplemented by the fly movement with pedestrians and vehicles, as indicated by the picket, it is certain that many flies entered the treated areas. It would have been most desirable if flies could have been marked in the main fly-belt, to see if any of them could have been re-captured in the treated woodland, but this was not possible with the very limited staff available during and after the experiment.

The reduction of 95 per cent. caused by the entire series of applications was

TABLE III.

Catches of flies upon the main fly-paths in Lango County, Uganda.

Period	Treated area						Control area	
	No. of individual searches	Average catch of <i>G. morsitans</i> per search					Average catch per search (5800 yd.)	
		Red Path (8200 yd.)	White Path (5900 yd.)	Blue Path (4700 yd.)	Pink Path (8700 yd.)	Green Path (6000 yd.)	All Paths (33500 yd.)	<i>G. morsitans</i> <i>G. pallidipes</i>
1953								
Jan.—Feb.	46	11.9	74.9	77.4	25.5	3.6	193.3	5.5
1st—2nd application	39	2.5	13.0	9.1	2.6	1.0	28.2	7.8
2nd—3rd application	35	0	21.2	6.0	4.0	0.8	32.0	12.0
3rd—4th application	26	0.25	2.2	0.3	1.2	0	4.0	12.5
4th—5th application	31	0.5	0.1	0.2	0.2	0	1.0	8.6
5th—6th application	26	0	0.2	0	0	0	0.2	9.3
6th—7th application	27	0.3	0.2	0	0	0	0.5	8.0
7th—8th application	33	0	0	0	0	0	0	5.5
July	43	0	0	0	0	0	0	21.0
Aug.	47	0	0	0.2	0	0	0.2	8.0
Sept.	49	0	0	0	0.1	0	0.1	4.8
Oct.	51	0.1	0.1	0	0	0	0.2	8.4
Nov.	49	0	0	0	0	0	0	9.5
Dec.	43	0	0	0	0	0	0	11.8
1954								—
Jan.	43	0.2	0	0	0.1	0	0.3	—
Feb.	48	0	0.2	0.1	0	0	0.3	—
Mar.	47	0	0	0	0	0	0	—
Apr.	47	0	0	0.1	0.1	0	0.2	—
May	51	0.1	0	0	0	0	0.1	—
June	52	0	0	0	0	0	0	—
July	21	0	0	0	0	0	0	—
Since 7th application	624	0.03	0.02	0.03	0.02	0	0.1	10.2
% of pretreatment average		0.2	0.03	0.04	0.08	0	0.05	186
								170

Total number of flies caught since the 7th application = 14.
 Total length of search since the 7th application = 2,400 miles.

not as high as in some of our previous work, but this may reasonably be attributed mainly to our inability to maintain and complete the cycle of applications, particularly in the later stages. There were also periods of several days when the atmospheric conditions were unfavourable, and there was a considerable leaf cover during the later applications, and both these factors may have contributed to a somewhat less efficient series of applications. The outstanding feature of the experiment, however, is that the fly numbers recovered quite rapidly to levels comparable to those of the original populations. In all our previous experiments, except one, the small residual populations have shown no obvious increase, and indeed have noticeably decreased in many cases. In the one exception, immigration was proved (Hocking, Parr & others, 1953a), and the increase was stopped when the main source of immigrants was removed. At Urambo, immigration was unfortunately not proved, but the possibilities for it were so great that the increase of the population there might reasonably be attributed to it, and not to a true recovery of an isolated population.

It is interesting to record that the method of development at Urambo was typical of what would be acceptable in any attempt to reclaim an extensive area of fly-infested woodland. Ideally, only land suitable for crops would be cleared, and inevitably this would leave pockets of infestation which would have to be eliminated before livestock could be kept. Wise after the event, it does not seem likely that insecticides, which cause no permanent change in the habitat, could remove these pockets in such a situation as was found at Urambo, where the experimental area was virtually an island in a sea of infested woodland, and where, too, there was so much traffic to and from the main fly-belt. Extensive barrier clearings could be made, and pickets could be established, but the risks of immigration would probably still be too high for the initial reduction to be maintained. For these reasons it is only the pockets of infested woodland left well behind by progressive development of a large area that can be treated with insecticides with a reasonable prospect of success.

The experiment in Lango County, Uganda, is a striking contrast to the one at Urambo. An enormous reduction in fly numbers was obtained and indeed it seems likely that the few specimens of *G. morsitans* caught since the end of the applications have been isolated wanderers from outside the experimental area, and that there is no established population. There were obvious possibilities for immigration, and the precautions taken against them undoubtedly reduced the number of immigrant flies to negligible proportions. Considering that, despite our precautions, each month several score of flies moved into the woodland to the north-west of the treated area, much of the continued success of the experiment must almost certainly be attributed to the fact that the woodland bordering the eastern side of the main road was inhospitable to flies, and that very few, if any, immigrant flies survived to reach the treated area.

Whereas it is usually possible to explain a failure in the control of an insect pest, it is often less easy to explain success. The experiment in Lango County was as successful as any in the entire series; *G. pallidipes* was eradicated and the population level of *G. morsitans* is now almost certainly less than one fly per square mile. Yet there were many factors that might have been expected to reduce the effectiveness of the applications. Meteorological conditions were usually not ideal, although rarely bad, and there was appreciable vegetation cover in the thickets; the runs were longer than in most of our other experiments, and this might have been expected to increase dosage variations and thus reduce kills, because of increases in the inevitable errors of flying in areas farthest from the markers, which in this experiment were the most heavily infested. Furthermore, a longer front between sorties might have been expected to increase the number of escapes by movement, although this might have been apparent rather than real because many overlaps between sorties occurred in sparsely wooded, partially

cultivated, strips where there were few flies. All that can be said of these various factors is that in the event their effect was slight.

Although the experiment was a success, and achieved better results than might have been anticipated, the Uganda Government, who paid for a major proportion of the costs of the work, were unwilling to consider dealing with the entire fly-belt in this way. Their refusal was undoubtedly because they considered that the cost—approximately £1,000 per square mile of treated woodland (see Yeo, 1954)—was too high, and that the entire fly-belt could be tackled adequately, and more cheaply although much more slowly, by methods based upon game eradication. Their attitude was also influenced by the fact that aircraft methods, although rapid in dealing with quite large areas, involve a high rate of expenditure; in other words, a small annual expenditure, spread over many years, is in Africa often more acceptable than an equivalent total amount spent over one or two years.

It is perhaps as well to point out that tsetse control measures are always expensive. Sheer clearing of woodland, probably still the only sure way of eradicating a tsetse population, is undoubtedly more expensive than our present insecticidal techniques; discriminative clearing, and methods based upon game eradication, are, on the other hand, usually considerably cheaper. The future of aircraft methods would be brightened if costs could be reduced appreciably, and if the final reductions were somewhat higher and more reliable; suggestions for achieving these two ends have been made elsewhere (Yeo, *op. cit.*).

The two experiments described in this paper are not likely to be followed by further aircraft applications against tsetse flies in East Africa until fundamental work has been done to improve the efficiency and reduce the costs of the method. It is, therefore, timely to summarise the results achieved so far, with reasons for the various successes and failures, and this will be done in a separate paper.

Summary.

Two experiments are described where applications of coarse aerosols have been made to areas of savannah woodland infested with tsetse flies (*Glossina* spp.).

The applications were made at nominal dosages of 0.25 gallons per acre, which was equivalent to either 0.20 lb. of p,p'DDT per acre, or 0.03 lb. of γ BHC per acre. The coarse aerosols had mass median diameters of approximately 60 microns.

In one experiment, carried out at Urambo, Tanganyika, a reduction of 95 per cent. was obtained in populations of *G. morsitans* Westw. This kill was somewhat lower than in many other experiments, a fact that can be attributed mainly to our inability to maintain the cycle of applications. Immigration of flies into the treated area caused a relatively rapid increase in fly numbers to levels comparable to the pre-treatment populations, and in this respect the experiment was a failure.

The other experiment, in Lango County, Uganda, was highly successful, and reduced a population of *G. morsitans* to 0.05 per cent. of its pre-treatment level, and eradicated a small population of *G. pallidipes* Aust. It is indeed likely that no stable population now exists in the area, and that the very few flies caught there since the end of the applications have been wanderers from other infested woodland. The continued success of the experiment is considered to be due to the effective isolation of the area.

Some brief comments are made upon the costs of the method, and on its value under conditions of land development in Africa.

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Much of the entomological work in Uganda, particularly the earlier surveys, was carried out by the Uganda Tsetse Control Department, and we are pleased to acknowledge the assistance of Mr. J. Y. Moggridge, Director, and Major V. C. I. Bradshawe, and also of Mr. P. A. Nelson who carried out the field work.

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The flying was very satisfactorily carried out by staff of Messrs. Airwork Ltd., who in Uganda helped to such an extent that for much of the time only one other European was stationed there.

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References.

- BURNETT, G. F. (1954). Bull. ent. Res., **45**, pp. 411-421.
HOCKING, K. S., BURNETT, G. F. & SELL, R. C. (1954a). Bull. ent. Res., **45**, pp. 613-622.
HOCKING, K. S., BURNETT, G. F. & SELL, R. C. (1954b). Bull. ent. Res., **45**, pp. 605-612.
HOCKING, K. S., PARR, H. C. M., YEO, D. & ANSTEY, D. G. (1953a). Bull. ent. Res., **44**, pp. 627-640.
HOCKING, K. S., PARR, H. C. M., YEO, D. & ROBINS, P. A. (1953b). Bull. ent. Res., **44**, pp. 601-609.
HOCKING, K. S. & YEO, D. (1953). Bull. ent. Res., **44**, pp. 589-600.
HOCKING, K. S., YEO, D. & ANSTEY, D. G. (1954). Bull. ent. Res., **45**, pp. 585-603.
JACKSON, C. H. N. (1949). Biol. Rev., **24**, pp. 174-199.
SWYNNERTON, C. F. M. (1936). Trans. R. ent. Soc. Lond., **84**, 579 pp.
YEO, D. (1954). Rep. 6th Commonw. ent. Conf., London, 1954, pp. 44-48.
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A DIURNAL RHYTHM IN THE EMERGENCE OF *PEGOMYIA BETAE* (CURTIS) FROM THE PUPARIUM.

By R. A. DUNNING

The Beet Fly, *Pegomyia betae* (Curt.), is a pest of sugar beet and related crops. Eggs are laid on the underside of the leaves and the larvae mine inside the leaves, causing loss of effective leaf area. Pupation occurs in the soil at an average depth of 2 in. Approximately five per cent. of the first-, 50 per cent. of the second-, and 100 per cent. of the third-generation pupae enter into diapause, not completing their development until the following spring. Under field conditions it was observed that the flies emerged from the puparia mainly during the early morning, thus supporting the findings of Blunck, Bremer & Kaufmann (1933). During a study of the biology, parasitism and control of the Beet Fly, experimental work was carried out on the emergence rhythm.

Emergence of Flies from Puparia kept under Field Conditions.

During June and July 1950, the progress of emergence of first-generation flies from three batches of puparia was recorded (Experiment 1). The puparia were obtained by water flotation from the soil on 14th June, at the end of the first-generation attack on fields in the Lowestoft area, and were kept under three muslin-covered cages at a depth of 2 in. in beds of soil on the roof of the laboratory. Emergence occurred between 20th June and 8th July; it was recorded at hourly

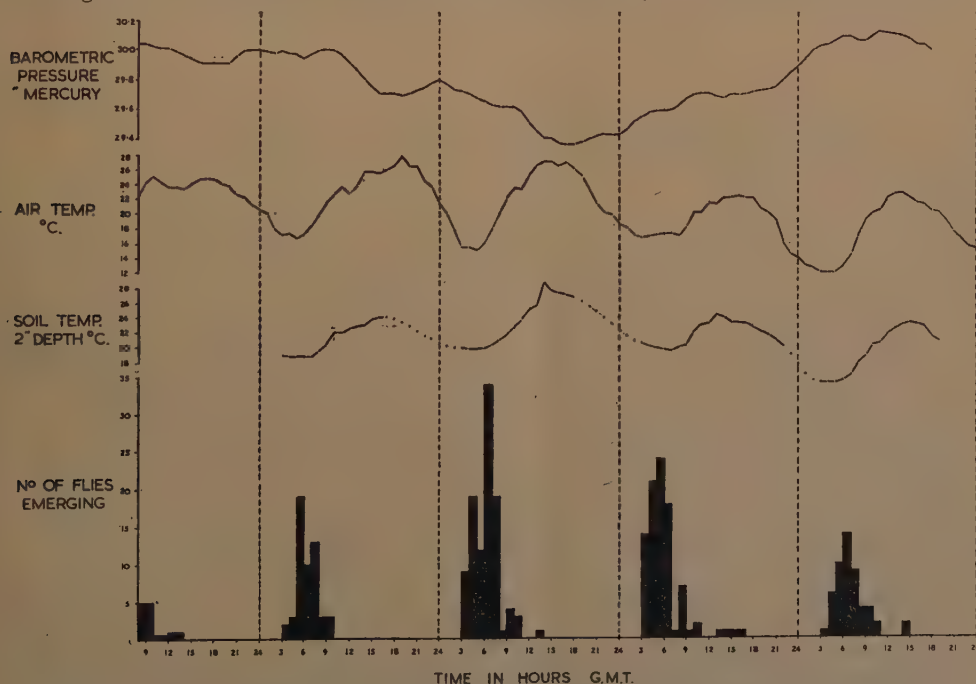


Fig. 1.—The diurnal rhythm in the emergence of flies from the soil (27th June (part)—1st July), related to barometric pressure and to air and soil temperature.

intervals from 08. to 20. hr. G.M.T.* over the period 23rd June to 27th June and from 03. to 20. hr. on the four days 28th June to 1st July. The soil temperature at 2 in. depth and the air temperature were recorded during the same periods, and the atmospheric pressure was obtained from local barograph traces. The daily emergence for the period 27th June (part)–1st July is shown in fig. 1 and for 23rd June–1st July in Table II.

The distinct rhythm of early morning emergence that took place during the period under observation is clearly shown in fig. 1. The combined hourly emergence over the four-day period is shown in Table I. No emergence occurred before

TABLE I.

Total hourly emergence of flies during the four-day period
28th June–1st July 1950.

Time (24 hr. clock)	No. of flies emerging	No. expressed as % of total emergence
03.—04.	26	8.7
04.—05.	49	16.4
05.—06.	65	21.7
06.—07.	76	25.4
07.—08.	42	14.1
08.—09.	15	5.0
09.—10.	12	4.0
10.—11.	7	2.4
11.—12.	0	—
12.—13.	0	—
13.—14.	2	0.7
14.—15.	3	1.0
15.—16.	1	0.3
16.—17.	1	0.3
17.—03.	0	—
	299	100.0
03.—08. inclusive	258	86.3
03.—12. "	292	97.7
03.—17. "	299	100.0

03. hr. or after 17. hr., the peak emergence being between 06. and 07. hr.; 86.3 per cent. of the total emergence (299 flies) occurred between 03. and 08. hr., and 97.7 per cent. between 03. and 12. hr., inclusive, on each day.

These results show a more marked rhythm of morning emergence than those given by Blunck, Bremer & Kaufmann (*loc. cit.*), whose figures were 79.2 and 95 per cent., respectively, for the same periods. When air and soil temperatures are considered, it is clear that the main emergence occurred at the time when these two factors were at about their daily minima. The barometric pressure trace shows no apparent correlation between pressure fluctuations and the emergence of flies.

Interesting variations that occurred in the daily rhythm of emergence of flies in this experiment are shown in Table II. During the first five days of the records the daily emergence to 08. hr., expressed as a percentage of the total day's emergence (hereinafter termed "08. hr. percentage emergence") rose gradually to the peak of 92.1 per cent. reached on the sixth day, whilst on the eighth and ninth days this percentage had fallen to 85.7 and 80.0, respectively. This variation is shown graphically in fig. 2, one curve being the "08. hr. percentage emergence"

* All times are given in hours G.M.T., and are written in abbreviated form for conciseness.

of the day's total for all three cages, and the other for cage B only. (Cage B accounts for 65 per cent. of the total emergence. Cages A and C have fewer flies emerging and do not show the variation so clearly. The totalling of emergence from all three cages also tends to produce errors, since the source of the puparia

TABLE II.

Daily emergence of flies: emergence to 08. hr. as percentage of day's total emergence.

Date (1950)	Cage A			Cage B			Cage C			Cages A + B + C		
	Total for day	Total to 08.hr.	% to 08.hr.	Total for day	Total to 08.hr.	% to 08.hr.	Total for day	Total to 08.hr.	% to 08.hr.	Total for day	Total to 08.hr.	% to 08.hr.
June 23	4	2	50.0	7	0	—	0	0	—	11	2	18.2
„ 24	1	1	100.0	8	3	37.5	0	0	—	9	4	44.4
„ 25	7	6	85.7	12	8	66.6	0	0	—	19	14	73.7
„ 26	14	10	71.4	16	13	81.2	1	0	—	31	23	74.2
„ 27	16	8	50.0	40	36	90.0	8	7	87.5	64	51	79.7
„ 28	13	12	92.3	27	25	92.6	11	10	90.9	51	47	92.1
„ 29	13	11	84.6	68	64	94.1	21	18	85.7	102	93	91.2
„ 30	26	20	76.9	57	51	89.5	8	7	87.5	91	78	85.7
July 1	10	8	80.0	37	31	83.8	3	1	33.3	50	40	80.0
Total emergence for period	104			272			52			428 352 82.2		
Total over six-day period 26th June to 1st July (cf. Table III)										389 332 85.3		

in each cage was different.) Emergence of flies did not cease until 8th July and it appears very probable that if the "08. hr. percentage emergence" record had been continued until this date, it would have continued to fall, making the curve more completely parabolic.

The emergence of flies of any generation shows an approximately normal distribution over the period and, in the case of the first generation at least, it may be concluded from the above results that during peak emergence of the flies 80-90 per cent. emerge from the soil before 08. hr. each day, but that earlier and later emergences during the period tend to occur later in the day.

Emergence of Flies from Puparia formed by Larvae kept in Darkness.

Since Blunck, Bremer & Kaufmann (*loc. cit.*) stated that temperature did not appear to influence the time of emergence, it was thought that the influence of daylight on the insect in the larval stage might affect the rhythm of emergence of flies from the puparia at dawn. Consequently, an attempt was made to keep larvae, as well as puparia, in the dark during as much of their developmental period as possible (Experiment 2).

Mined leaves containing larvae in various stages were collected on 19th July during a second-generation attack in 1950. All larvae obviously mature and about to pupate were first removed and the leaves were then placed in a closed bin on the roof of the laboratory on 20th July, moist soil being scattered liberally between and around the leaves. Under these conditions the leaves remained quite fresh for about a week, and allowed many larvae to complete development and pupate.

Larvae that were half-grown or more at the time of collection were able to pupate normally, whilst younger larvae would have had to pupate prematurely, due to the rotting of the leaves. On 8th August, 560 puparia were sorted from the soil and rotting leaf debris and, on 9th August, were placed at a depth of 2 in. in soil under a muslin cage on the roof of the laboratory. The puparia had only been

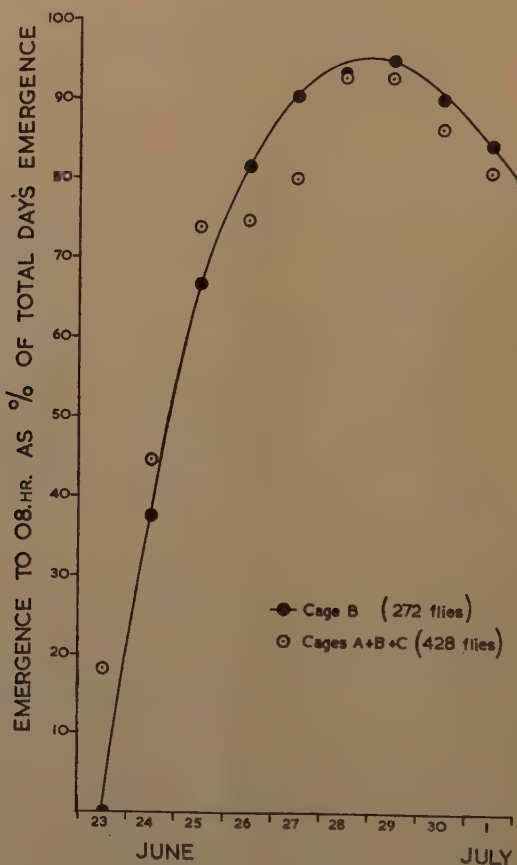


Fig. 2.—Variation in the diurnal rhythm of emergence of flies from the soil over a period of nine days; the number emerged daily to 08. hr. G.M.T. expressed as a percentage of the day's total emergence.

exposed to light during the periods 09.–11. hr. on 8th August and 17.–18. hr. on 9th August, whilst the larvae had been in the dark for periods varying from ten or more days to a minimum of about half a day. The main emergence of flies was recorded and the "08. hr. percentage emergence" determined (Table III).

For comparison, a sample of puparia was floated from the soil in the same field on 1st August at the end of the second-generation attack, but parasitism, mortality and the onset of diapause reduced the total emergence to too low a level for satisfactory comparison.

The "08. hr. percentage emergence" of the adults of the non-diapausing part of the second generation (Table III) over the six-day period was only slightly less than that obtained for the peak six days of the first-generation emergence in Experiment 1, being 79.1 per cent. as compared with 85.6 per cent. There was

again a tendency for the peak emergence to show a higher "08. hr. percentage emergence" than did the earlier and later emergences during the total period of fly emergence.

These results suggest that the rhythm of emergence is not induced by the

TABLE III.

Emergence of flies from puparia formed by larvae kept in darkness.

Date (1950)	No. of flies emerging		"08. hr. per centage emergence"
	00. to 24. hr. total	03. to 08. hr. total	
August 11	29	19	65.5
August 12	35	28	80.0
August 13	48	40	83.3
August 14	49	40	81.6
August 15	28	23	82.1
August 16	12	9	75.0
Total over six-day period	201	159	79.1%

effect of the daily light rhythm on the late larval stage. However, the early larval stages were exposed to daylight and the rhythm might possibly have been induced then.

Emergence of Flies from Puparia kept at Constant Temperature.

In order to check the contention of Blunck, Bremer & Kaufmann (*loc. cit.*) that temperature does not appear to influence the hours of emergence, the following experiment was carried out (Experiment 3).

Three batches of 225 first-generation puparia, obtained from the soil on 2nd July 1951, were kept under various conditions of temperature, as shown in fig. 3. The emergence of flies was recorded each day at two-hourly intervals from 08. to 20. hr. over a forty-day period, beginning on 5th July when emergence started. It was not possible to make records from 20. to 08. hr., and emergence between these two times has had to be averaged over this twelve-hour period. From puparia at a depth of 2 in. in soil outdoors the normal rhythm of early morning emergence occurred, *i.e.*, 85.6 per cent. before 08. hr., and it may be presumed that the actual peak emergence occurred at about 06. to 07. hr., as in previous experiments (Nos. 1 & 2). In the case of puparia kept at constant temperatures of 10 and 25°C., however, only 29.1 and 33.6 per cent., respectively, of the flies emerged during the twelve-hour period up to 08. hr. The constant temperatures, to which the puparia were subjected only during the latter period of their development, produced a much less pronounced rhythm of emergence occurring later in the day. This conflicts with the conclusion of Blunck, Bremer & Kaufmann (*loc. cit.*) that temperature does not appear to influence the time of emergence.

Observations at the end of August 1951, on the emergence of the adults of the non-diapausing part of the second-generation flies from another batch of puparia kept at a depth of 2 in. in soil outdoors, again showed that the majority (76.3%) of the flies emerged before 08. hr. each day.

The Time taken for freshly emerged Flies to work their way through Soil.

In the first three experiments, only the time of appearance of the flies at the soil surface has been considered (except in No. 3, in which those puparia at constant temperatures were lying on the surface of moist sand in petri dishes). However, in the determination of possible factors initiating rhythmic emergence, the approximate time taken for the flies to reach the surface of the soil after emergence from the puparium must be known (Experiment 4a).

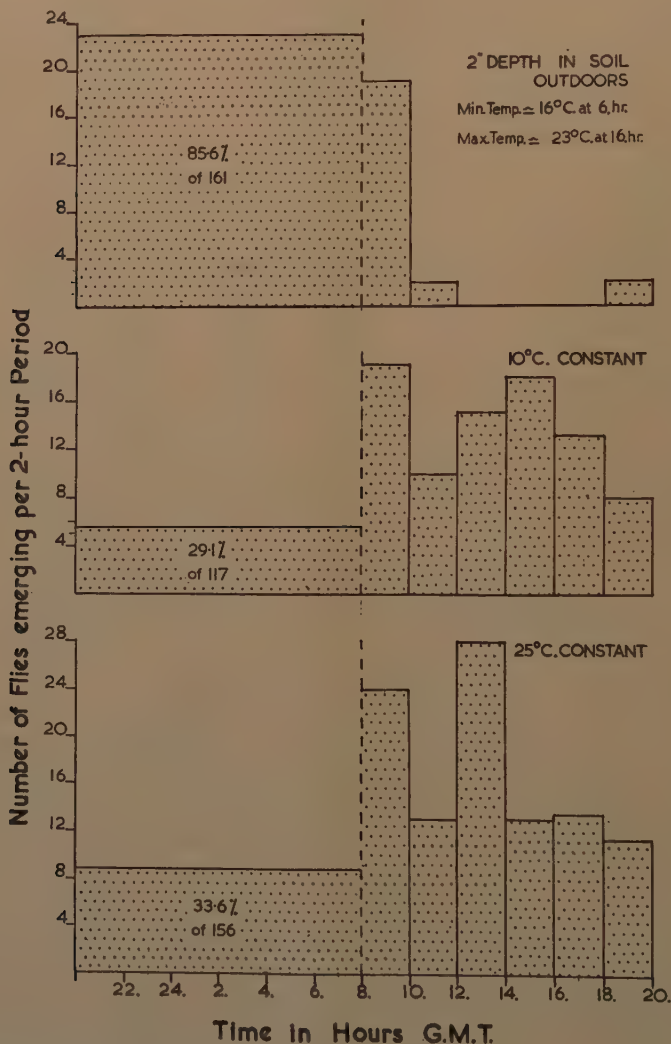


Fig. 3.—The diurnal rhythm of emergence of adults over a forty-day period; pupae kept under different temperature conditions.

A batch of puparia was kept on moist sand in a petri dish at room temperature. Flies freshly emerged from these puparia, and with wings still unexpanded, were carefully buried in sand or soil at various depths, including some greatly in excess of 2 in., and the time of their reappearance at the surface observed.

Experiments were carried out at 20°C., and in all cases where flies did not appear at the surface, investigation showed that they had hardly moved from the position where originally placed. The flies placed at 2 in. depth in loose moist soil reached the surface in periods varying from 12–40 minutes. In the following list the number of flies reaching the surface from depths of $5\frac{1}{2}$ in. and $8\frac{1}{2}$ in. and attaining normal adult form is shown as the numerator and the number of flies used as the denominator of a fraction. The low proportion of flies reaching the surface may be attributed to slight delay in placing some in the soil or sand.

Moist, loamy soil:	1/5	surfaced from	$5\frac{1}{2}$ in.	in less than	$1\frac{1}{2}$ hr.
Dry sand:	1/2	"	"	"	2 hr.
"	2/4	"	$8\frac{1}{2}$ in.	"	$2\frac{1}{4}$ hr.
"	1/2	"	"	"	$\frac{1}{2}$ hr.

From these results it can be assumed that, at 20°C., 2 in. of soil (the normal depth of pupation) will be traversed in less than one hour, provided the soil is reasonably moist and loose, conditions which were fulfilled in all the previous experimental work. In dry, baked soil, flies would be unable to emerge at all, except by way of cracks. Soil temperatures at a depth of 2 in. were between 16 and 20°C. at the time when peak emergence was occurring in Experiment 1 (end of June).

The Time taken for freshly emerged Flies to reach their normal Adult Form.

Batches of freshly emerged flies, with their wings still unexpanded, were subjected to different conditions of temperature and humidity and note was made of the time that elapsed before the normal adult form was reached (Experiment 4b).

Observations made on the emergence of flies from puparia lying free on moist sand in petri dishes (*i.e.*, at almost 100% R.H.) showed that, at 25°C., the flies expanded and dried their wings, resorbing the fluid contents, within one hour, whilst at 20 and 15°C. this period was extended up to as long as two hours. At 10°C. the process was usually completed within two to three hours, but some flies made no attempt to expand their wings, yet did so in a normal manner within a short time of transference to 20°C. and a lower humidity. On leaving such flies at 10°C. and high humidity for periods of 24 hours before transference to 20°C. and a lower humidity, normal expansion could still be obtained easily and, in one case, 39 hours elapsed before the fly (a male) was removed to these conditions, where it expanded and dried its wings normally within one hour. Freshly emerged flies kept in an air stream at 17.5°C. and 54 per cent. R.H. failed to expand their wings fully, due to premature drying and hardening, yet, as was shown above, two flies spent some two hours in air-dried sand and were then able to expand and dry their wings normally. Fraenkel (1936) showed that, in *Calliphora*, flies that were kept digging through soil for as long as seven hours still remained pale and soft, inflation, hardening and darkening occurring normally when they became free. He concluded that, during digging, these processes are inhibited by some nervous mechanism, and this conclusion clearly satisfies the results of the present writer's work with *P. betae*, only excessive dryness preventing normal expansion of the wings, a condition which might well occur should the flies emerge in the middle of the day rather than in the early hours of the morning.

Discussion.

A diurnal rhythm of emergence may be caused by:—

- (a) External physical factors, themselves having a diurnal rhythm, acting directly when the fly is ready for emergence.

- (b) The same external factors, influencing some earlier stage, *i.e.*, parent adult, egg, larva or early pupa, so as to induce an autonomous rhythm that persists even when these factors are kept constant at the time of emergence.
- (c) An inborn rhythm in the species itself, probably induced by external factors, but which persists for at least one generation under constant conditions.

Scott (1936) discusses the various factors having a daily periodicity, namely, temperature, light, barometric pressure, relative humidity, electrical potential and electrical conductivity. He concludes that the first two named, having by far the greatest diurnal fluctuations, are the most important factors to be considered in connection with emergence rhythms, and that the remaining factors may be disregarded since their rhythms are very slight, and either dependent on temperature or occur twice daily.

The writer agrees with Scott's conclusions and, for flies emerging from puparia buried at a depth of 2 in. in soil, it is clear that the only factor governing directly the rhythmic emergence at dawn can be soil temperature at that depth. In Experiments 1, 2 and 3 the minimum soil temperature usually occurred just before the peak diurnal emergence, but this is unlikely to be the cause of emergence since the fly cannot detect that the minimum has been reached. Falling temperature may be the cause, since it is falling over some ten hours and emergence occurs over some eight hours, but if this is the cause, then a lag of some eight hours between initiation of emergence and appearance at the soil surface has to be accepted. Again, initiation of emergence may occur when the temperature begins to fall, but this would indicate a time lag of at least twelve hours. Commencement of emergence of the fly from the pupa might take place a considerable time before actual emergence from the puparium, but this seems unlikely. Scott showed for *Ephestia* that maximum emergence occurred shortly after the temperature began to fall. If temperature is the direct cause of the rhythm of emergence of flies, then the most likely explanation is that emergence is initiated when the temperature begins to rise immediately after the minimum has been passed, and that there is very little time lag between initiation of emergence and actual appearance at the soil surface. Soil temperature records taken during emergence outdoors (fig. 1) do not, however, support this theory, since on the third day the soil temperature was still falling during the greater part of the emergence.

Furthermore, if rhythmic emergence is solely dependent on the direct influence of a temperature rise, it would be expected that at constant temperature emergence would be comparatively even throughout the day; the results of Experiment 3 showed only a partial levelling off of the rhythm of emergence at constant temperature. Thus, although under normal conditions in the soil outdoors the emergence may well be "triggered" by a diurnal temperature variation, the rhythm persists to a certain extent, although delayed, even when there is no such variation in temperature. Observations on the emergence of flies under field conditions (Experiment 1) also showed that the straggling earlier or later emergence during the period of emergence of flies from a batch of puparia tended to occur later in the day than did the peak emergence during the same period, indicating an autonomous rhythm influencing the majority, but not all, of the pupae.

Results obtained could be explained by the suggestion that the rhythm is induced by rhythmic fluctuations of light or temperature at some time before the late pupal stage, or that it might even be inborn in the species itself, and that this autonomous rhythm is regulated by temperature variation at the time when the fly is ready to emerge from the puparium. Further work will be necessary before the suggested explanation can be shown to be valid or otherwise.

The optimum conditions for the appearance of the flies at the soil surface occur at the time of minimum temperature and maximum humidity. Should they emerge at midday when temperature is high and humidity low, especially at the height of summer, the flies might have difficulty in reaching their normal adult form, as was shown in Experiment 4b.

Summary.

There is a clear diurnal rhythm in the emergence of the Beet Fly, *Pegomyia betae* (Curt.), from the soil, peak emergence occurring daily between 06. and 07. hr., when the soil temperature at a depth of 2 in. and the air temperature are at about their minimum, or are just beginning to rise, and humidity is at its maximum. In two observations on the emergence of the first generation, 82.2 and 85.6 per cent. of the daily emergence occurred before 08. hr., whilst in two observations on the emergence of the adults of the non-diapausing part of the second generation, 79.1 and 76.3 per cent. of the daily emergence occurred before 08. hr.

During the period of emergence of flies from a batch of puparia, the rhythm was most marked at the time of peak emergence, and was less marked at the beginning and end of the emergence period.

The rhythm of emergence was much less pronounced, and the peak occurred later in the day, when puparia were kept at constant temperature from two days before the first flies emerged.

Experiments led to the conclusion that the fly reaches the soil surface within one hour of leaving the puparium at a depth of 2 in. in soil, and that the processes of wing expansion and cuticle tanning are probably controlled by a nervous mechanism.

The possible initiators of the diurnal rhythm are discussed. It is concluded that the results obtained could be explained by the suggestion that the rhythm is induced by the effect of temperature or light fluctuation at some time before the late pupal stage, or that it might be inborn in the species, and that it is further regulated by temperature variation at the time of emergence. Further work will be necessary before the suggested explanation can be shown to be valid or otherwise.

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References.

- BLUNCK, H., BREMER, H. & KAUFMANN, O. (1933). Untersuchungen zur Lebensgeschichte und Bekämpfung der Rübenfliege (*Pegomyia hyoscyami* Pz.). II. Mitteilung.—*Arb. biol. Reichsanst.*, **20**, pp. 517–585.
- FRAENKEL, G. (1936). Observations and experiments on the blow-fly (*Calliphora erythrocephala*) during the first day after emergence.—*Proc. zool. Soc. Lond.*, **1935**, pp. 893–904.
- SCOTT, W. N. (1936). An experimental analysis of the factors governing the hour of emergence of adult insects from their pupae.—*Trans. R. ent. Soc. Lond.*, **85**, pp. 303–330.
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THE OCCURRENCE AND DISTRIBUTION OF *APHOMIA GULARIS* (ZELL.) (LEP., GALLERIIDAE), A PEST OF STORED PRODUCTS.

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(PLATE XII.)

Though the majority of insects which are important pests of stored produce are now established in those parts of the world where climatic conditions are suitable, the countries of origin of most are either unknown or can only be surmised. Information concerning the spread of a number of the better known species has been summarised (Zacher, 1939*b*) and the methods by which dispersal takes place have been described in detail (Freeman, 1948, 1950). *Aphomia gularis* (Zell.), whilst not yet of world-wide distribution, has already become a serious pest in some of those countries where it is established, and its continuing spread furnishes an interesting example of dispersal taking place through normal trade channels. The purpose of this paper is to summarise the available information regarding its bionomics and to put on record new observations relating to its biology and dispersal to date, with special reference to its occurrence in Britain.

Bionomics.

Food preferences and damage to produce.

There are no records of the original habits of this species, though as a pest of stored produce it is known to feed on cereals, pulses, dried fruit, oilseeds and nuts. Almonds, walnuts, groundnuts and prunes are especially attacked as are, to a lesser extent, rice and grain. The damage done is often considerable and costly. That caused to nuts for confectionery purposes is particularly so because of the value of these commodities. When almonds and groundnuts are attacked, much of the testa is consumed and a high percentage of the embryo eaten away (Pl. XII, fig. 2). In California, where it is recorded as the most destructive pest attacking prunes (Donohoe, 1946), it is reported that the flesh of individual prunes is completely destroyed and that damage occurs at a depth of many feet in bins of closely packed unprocessed fruit. Fouling by the conspicuous and profuse webbing and frass is also considerable and both wooden bin walls and boxes in which the fruit is packed may be badly damaged by the boring of the larvae prior to pupation. No information is available of the damage caused to grain though it has been noted as serious in China (Yang, 1934), and in Japan (Kono, 1940). Elsewhere, in the U.S.A. (Linsley & Michelbacher, 1943), Canada (Gray, 1953), Germany (Zacher, 1941) and in Britain, only slight attacks have been reported.

Life-cycle.

Though a general description of the life-cycle has been published (Jacobs, 1935) there are few records of development periods under controlled conditions. It is known, however, that eggs take 4 or 5 days to hatch at 30°C. and 70 per cent. R.H. (Liebers, 1937) and at 18° to 20°C. a generation takes six months (Zacher, 1935*a*). At 24°C. and 56 per cent. R.H. a generation has been found

by the author to take 12 to 15 weeks. These latter temperature and humidity conditions enable continuous breeding to take place, though other than under heated conditions it is usual in both Europe (Zacher, 1935b) and North America (De Ong, 1919) for there to be only one or two generations a year.

The eggs (Lehmensick & Liebers, 1937), larvae (Hinton, 1943) and adults (Amsel, 1937) have been described in detail. An individual adult is recorded as producing 150 to 250 eggs (Liebers, 1937) which are cemented singly or in groups onto the foodstuff. On almonds, a female was observed by the author probing with its ovipositor to place each egg in cracks or faults in the testa.

In five unheated London warehouses which have been kept under observation for a number of years by inspectors of the Ministry of Agriculture, adults (Pl. XII, fig. 1) have been active in the months of June and July and exceptionally in May. Occasionally, adults of a second generation have been found in August and September.

In the same warehouses active larvae (Pl. XII, fig. 2) have been found from June to November, though by October and November the majority have spun cocoons. When fully grown, the larvae become increasingly active for a period of between 6 and 20 days during which time they migrate in numbers from food stacks. Cocoons, which are thick and tough, are usually to be found in conspicuous groups of up to 60 or more spun together in corners, in cracks in brickwork, or beneath loose wall fittings, though a few may be found in the stack spun up between sacks.

Ecdysis occurs inside the cocoon soon after it has been formed, the resulting exuviae being sealed in at one end on the completion of the inner lining. The mature larva differs from earlier instars in being a pale yellow in colour and in not having dark pinnaculæ on thorax and abdomen. In this stage they remain in a state of diapause until April when pupation takes place, a habit which is similar to that observed under unheated conditions in Germany (Müller, 1939).

Larvae become torpid when kept at temperatures in the region of 0°C. but recover after several weeks of such treatment when returned to normal conditions. On the other hand, eggs kept at temperatures between -3°C. and +4°C. for six months fail to hatch (de Loverdo, 1907).

Natural enemies.

Two Hymenopterous parasites have been recorded, *Bracon hebetor* Say in the U.S.A. (De Ong, 1923, as *Habrobracon juglandis* Ashm.) and a species of *Trichogramma* introduced into Japan from the Philippines for experimental purposes (Shibuya & Yamashita, 1936). Parasitism by the former species has also been observed in London.

In the U.S.A. the pathogenic spore-forming bacillus, *Bacillus thuringiensis*, has been isolated from a diseased larva (Steinhaus, 1951).

Occurrence and Distribution.

Origins.

Originally described from specimens from Japan (Zeller, 1877, p. 74; Butler, 1879), it has subsequently been recorded from Sikkim (Hampson, 1898), Bhoutan, China (Ragonot, 1901, p. 475), Madras (Hampson, 1917), Vladivostok, U.S.S.R. (Laing, 1922), and Manchuria (Müller, 1939). In China specimens were taken in Lungtan, Kiangsu (Caradja & Meyrick, 1935), and it has been noted as an important pest of grain in Western Kiangsi (Hsiu, 1936) and in Sioshan, Chekiang (Yang, 1934). At the latter place it was found generally during a survey of fifty houses storing that commodity. Other specimens have been collected from Shanghai, Nanking (de Joannis Coll., Paris), Chang-Yang, Hupeh, at 1,000 ft. at Chia-Ting-Fu, Kiangsu, and on Omei-Shan, Szechwan, at 3,600 ft. (Brit. Mus.

(Nat. Hist.) Coll.). There is, however, no record of it attacking groundnuts in these places, which is surprising when the circumstances of its introduction into the U.S.A. and its habits elsewhere are considered.

In Japan, reference has been made to it as a pest of rice (Kawano, 1939) and stored grain (Kono, 1940), while specimens have been taken in Kyushu, Shikoku and Honshu (Brit. Mus. (Nat. Hist.) Coll.).

Though there is no published information regarding the insect's occurrence elsewhere in Asia, specimens have been taken at 5,000 ft. at Chapa, North Vietnam, Indochina (de Joannis Coll.), at 6,000 ft. at Hiawgaw and Washan, Upper Burma, and Belgaum, Bombay (Brit. Mus. (Nat. Hist.) Coll.).

A comparison made between this widespread distribution throughout south-eastern Asia and its occurrence elsewhere, which with few exceptions is localised to the vicinity of the major ports of western Europe and North America (fig. 1), leaves little doubt that the species originated in that region.

Dispersal and introductions.

Notwithstanding the availability of other countries with suitable climatic conditions for its development, the speed of dispersal of a localised pest of stored products must in the first instance be dependent on the flow of infestable goods from the country of origin. When, however, further centres of infestation have become established any deficiency in this respect may cease to be a controlling factor. This would appear to have been the case with *Aphomia gularis*.

With this species the trade in infestable foodstuffs between the presumed countries of origin and the rest of the world has never been great, while during and since the last war it has diminished still further. Of the goods concerned, Chinese and Japanese beans and rice would seem to have been the most likely to be infested, while the export prior to 1939 of Chinese and Manchurian oilseeds such as groundnuts and soya beans may have been a further line of dispersal. It is, however, significant that the few records available of this pest being intercepted on imports are from countries importing the bulk of such goods, namely the U.S.A., Germany and Britain.

The earliest record is from Britain, where larvae were intercepted in London on Japanese rice (Jenner, 1892). It was on that same commodity, as well as on Japanese beans and Chinese rice that the species was discovered and controlled in Hawaii (Swezey, 1913; Ehrhorn, 1915-18). It was imported into California on Chinese groundnuts (De Ong, 1919), into Germany on Manchurian soya-bean meal (Müller, 1939) and more recently into Britain on Chinese apricot kernels.

These are the only known records but there seems little doubt that introductions have been taking place from time to time into other countries. Thus by 1907 the insect was recorded from France as having been a serious pest in almond stores in Provence for many years previously (de Loverdo, 1907); it was first recorded from Canada in 1934 (MacNay, 1952a), Holland in 1938 (Diakonoff & de Boer, 1938), Sweden in 1950 (Ander, 1951), and Sicily in 1951 (Silvestri, 1951).

The case of the Spanish almonds found at Worcester in 1953 to be infested after only one week's transit storage in an infested London warehouse illustrates how spread of infestation is taking place on goods which, though imported from uninfested sources, acquire infestations whilst passing through infested port warehouses. A further development in this chain of dispersal is establishment in areas away from the ports where infestable goods are produced for export. Such centres of infestation would account for the interception on import into Britain in 1955 and 1956 on two shipments of Lombardy rice from Genoa, on one of Turkish hazel-nut kernels from Giresun, and on numerous ones of French shelled walnuts from Bordeaux, as well as that on the latter commodity from Marseilles (Laing, 1922).

Unless action is taken to wipe out these and other centres of infestation and



Fig. 1.—Map showing distribution of records of *Aphomia gularis* (Zell.).

an effort made to prevent the export of infested goods from such regions a further spread can be expected to countries at present not affected. Fortunately, some action is already being taken in this respect, the introduction into New York in 1955 on Bordeaux shelled walnuts having been prevented by the fumigation on export of two shipments seen at Liverpool whilst in transit.

Apart from such action on the part of exporting countries, Egypt has set a lead by introducing legislation which specifically prohibits the importation into that country of produce infested with *Aphomia gularis* (Anon., 1956).

Establishment.

In North America, following the initial introduction into California, there is only one reference to it (Essig, 1921) until a survey of prune-processing plants was carried out between 1927 and 1937 (Donohoe, Simmons & Barnes, 1938). During the seven years from 1927 only one plant was found infested in the San Jose area, but in 1935 several plants in the same region were affected, as was one in Oakland. By 1936-37 all the plants visited were infested to a serious extent.

In 1946 it was still recorded in the San Francisco Bay region where, apart from being the most destructive pest of prunes, it was found occasionally attacking peanuts and almonds (Donohoe, 1946). Prior to this, a survey of granaries in the whole of California had revealed it as present only in those in the southern interior where it was a minor pest (Linsley & Michelbacher, 1943).

The first Canadian record was in 1934 when it was taken in a Montreal warehouse (MacNay, 1952a). No information is available as to its status in that city though reports of infestations in a flour warehouse on the premises of a bakery supply firm in Vancouver (MacNay, 1952a, 1952b, 1953) and in two warehouses in Victoria storing rye and milled cereal products (Gray, 1953) would suggest that it is established in those western Canadian ports.

In Europe, the first recorded established infestation is undoubtedly that in the Provence region of France. Elsewhere in that country there are reports of the capture of specimens in Paris and Bordeaux (Le Marchand, 1928) though only at the latter port is there any confirmation of it possibly being established in the town and dockside warehouses (Lhomme, 1935). It was from that port that the infested shelled walnuts seen at Liverpool during 1955 had been shipped. However, the frequency of the interceptions between July and December suggested that the species is established in the Dordogne region where the nuts are processed. This conclusion has since been confirmed by Dr. J. Bruneteau of the Plant Protection Service, Bordeaux.

As regards other countries, apart from Britain which will be considered later in more detail, most of the observations are from Germany. The first record is from Karlsruhe (Kabis, 1908) where in 1907 a substantial infestation was observed on Sicilian almonds stored in a local warehouse. The subsequent mention of this species as a European one (Hofmann, 1910) was probably based on this record. In 1932-33 it was noted for the first time as endemic in a Hamburg cocoa warehouse and later in one storing dried fruit and nuts (Zacher, 1933, 1934). In the latter case there was evidence that the infestation had been established for some years. In 1936 a Hamburg marzipan factory was found to be infested (Weidner, 1936) and two years later insects from Manchurian soya-bean meal infested the transit sheds in the same port (Müller, 1939). There is, therefore, strong evidence that by the 1930's Hamburg had become a serious potential source of infestation for the large traffic of goods passing through it to the rest of Germany, the Baltic countries and elsewhere. The occurrence in a Malmö, Sweden, confectionery factory (Ander, 1951), and the spread to the rest of Western Germany is not therefore surprising. In 1938 it was first recorded in Germany on cereals,

namely rye in Berlin (Zacher, 1939a) and later, as a result of a survey, a small number of specimens were sent in from West German granaries (Zacher, 1941).

From Holland there is only one record, for an old dried-fruit warehouse, storing nuts, in Amsterdam, where the insect was undoubtedly established (Diakonoff & de Boer, 1938; Briejër, 1939).

Though reported as having occurred in Sicily (Silvestri, 1951) the author is informed by Dr. Gino Dal Monte of the Gabinetto Analisi Entomologia, Rome, that the species no longer occurs in that region.

While there are no other published records from elsewhere in Italy, the cases of the interception in Britain on polished Lombardy rice, in which there was no evidence that the infestations could have been acquired after shipment, may be taken as strong evidence that this species occurs in the northern part of that country.

There are also no published records available from Turkey. Its occurrence there, suspected after the interception in Britain in 1955 on hazel-nut kernels shipped from Giresun, has, however, been confirmed in correspondence by Professor B. Alkan of Ankara who reports that in 1954 he identified as *Aphomia gularis* a larva found on the same commodity from that port.

Though it was first taken in the United Kingdom in 1891 on Japanese rice at London *ex* ship and was even then recognised as a serious potential granary pest, there is no further reference to it until its importation on Marseilles walnuts and subsequent discovery at Bournville in 1922. In 1930, specimens were obtained breeding on Algerian almonds from a London warehouse (Richards, 1931) and a single adult specimen was found in Moor Lane, Finsbury, in 1932, having apparently originated from adjacent importers' warehouses. Others were obtained from peanuts in a private house in Upper Norwood, and a further specimen was found in the New Forest district (Wakely, 1932, 1933). These records were noted as somewhat exceptional, though soon after in London a strong endemic population was found on the premises of an Eastcheap date packer, as were a few larvae in dried-fruit warehouses at Millwall (Jacobs, 1933, 1935). From that time until 1942, when the Ministry of Food (now Ministry of Agriculture, Fisheries & Food) Infestation Control Division came into being, there is no information as to the insect's status. It was not recorded in a survey of insect pests of dried fruit in a number of London dried-fruit and nut warehouses (Richards & Herford, 1930), neither was it found during a grain-pest survey made during 1938-39 (Munro, 1940) nor numbered amongst the insect pests found in railway warehouses at that time (Hayhurst, 1940). From then on, however, a comprehensive routine inspection of all the large public warehouses, of many of the small ones and the majority of goods on import has enabled its position to be clarified. By 1942, the premises in Eastcheap visited by Jacobs had been destroyed and a regular inspection up to the present has failed to reveal this species in any Millwall warehouse. In 1952, an infestation was discovered on the premises of a wholesale dealer in dried fruit in Eastcheap, but this had most likely been acquired through trade with a large warehouse and nut-cleaning mill in Bermondsey known since 1942 to have a substantial infestation which it is said was first noted by the staff in 1937. The only other premises known to be affected in 1942 was a granary adjacent to this warehouse; in it occurred one of the only two recorded instances in Britain of the insect attacking grain, the other being in a Millwall granary (Richards & Waloff, 1947). Owing to their close proximity, there is little doubt that there was an interchange of insects between the granary and the nut warehouse, but whether the infestation on the grain depended on continual re-introduction from the warehouse is uncertain. There is no doubt, however, that, with the exceptions already noted, all the recent British records refer to the attack of nuts of one sort or another and occasionally to cocoa and

dried fruit, even though in a number of cases such apparently acceptable commodities as soya beans, beans and grain have been exposed to infestation without ill effect. Thus, in 1944, an infestation occurred in a Rotherhithe warehouse previously storing grain and cocoa after groundnuts and almonds were taken in. This infestation lasted only as long as such goods were stored and apparently died out in 1946 when the firm returned to its former trade. The origin of that particular infestation was not determined. At that time, the little produce which was being imported from potential sources of infestation was all inspected prior to discharge from the ship so that control measures might be applied where necessary, and as no stages of *Aphomia* were found to suggest import from abroad it would seem likely that cross-infestation had taken place. Under normal conditions there is generally very little interchange of goods between warehouses but in this instance there was a nut-cleaning mill attached to the infested one. During the war and immediately afterwards, nuts for confectionery purposes were very scarce and as a consequence many of a poor quality with much extraneous matter had to be taken. Hence, with the need for screening increased, it would not be surprising if goods acquired an infestation whilst passing through infested premises used for such purposes. As will be seen later, such premises have been shown to be connected with the dispersal of this insect in Liverpool. On the other hand, such premises are themselves liable to acquire infestations from infested goods sent to them for cleaning. This was the case when in 1951 a Wapping warehouse with a cleaning mill acquired an infestation from groundnut screenings stored pending delivery to an oilseed crusher. Fortunately, that particular infestation died out through lack of suitable food after the screenings were removed.

Though the original premises in Bermondsey continued to carry an endemic population there were no further outbreaks until 1950. In that year *A. gularis* became established at a large dried-fruit and nut warehouse at Southwark and was introduced on infested nuts into another, not regularly carrying such goods, in the same district. As in the case already quoted this latter infestation died out on the removal of the infested nuts. By that time the postwar trade in nuts had increased with the partial decontrol of imports and, with a subsequent less extensive inspection, insects may have been introduced unreported into this country. This possibility is confirmed by the number of interceptions of the species on imports since 1954. In any case, there was a further outbreak in another large Bermondsey nut warehouse in 1951 which rapidly attained serious proportions notwithstanding measures taken against it. Since then there have been instances of isolated insects being found in two other similar warehouses, one in Bermondsey and the other in Wapping, of which at least the former has particularly close trade relations with the original infested one in Bermondsey.

Thus with the destruction during the war of the infested Bermondsey granary, the species is at the present time firmly established in two and probably three warehouses in Bermondsey, one in Southwark and a wholesale premises in East-cheap, all of which are principally concerned with the storage of edible nuts. The result of this has become serious as a high proportion of such goods for manufacture in the factories of the north-west of England passes through those very warehouses and in this way insects are continually being dispersed. An example was the outbreak which occurred in a private nut warehouse near Worcester which had not previously been infested by this species. A considerable migration of *Aphomia* larvae occurred in the autumn of 1953 from a parcel of almonds which had been stored for a single week during the previous June in the infested Southwark warehouse. Further, a survey of edible-nut processing firms in the north-west revealed endemic populations in almond mills at Ancoats and Liverpool, of which that in the latter was of serious proportions. Similarly, the premises of nut-processing and confectionery firms at Salford, Radcliffe,

Garston, Golborne, Manchester and Liverpool were found to be infested. All these firms had direct trade contacts with the infested London warehouses, drawing from them much of their raw materials.

In the cases mentioned, doubt regarding the origin of the infestations was slight. The occurrence of *Aphomia* adults in 1950 in a Stockport provender mill, and of larvae in 1952 in two widely separated general warehouses in Liverpool, was more difficult to explain. It was found, however, that the two latter cases were connected in that the goods on which they were discovered, namely West African groundnuts and Indian apricot kernels, had passed through the warehouse of a local seed and edible-nut cleaning mill during the previous June, the one for screening and the other for rebagging. A visit to these premises revealed an endemic population, the adults from which would have been flying as the goods in question passed through. As with all the other cases, this firm admitted having done business with *Aphomia*-infested London warehouses. Apart from cleaning nuts, the firm does considerable business picking and screening peas and other seeds and it was learnt that, from these processes, screenings and the like are sold to provender mills. Though no direct connection between this particular firm and the Stockport provender mill could be found, the occurrence in these latter premises was probably due to the traffic in infested screenings and pickings from elsewhere. An instance of such dispersal was discovered following the visit to one of the other Liverpool seed cleaners. Though that firm had ceased to clean nuts since 1950 and was concerned solely with the production of bird seed, a few bags of groundnut screenings remained and they were moderately infested with *Aphomia* larvae. It was known that, before cleaning, the particular shipment of groundnuts had not been infested and that the firm's nut-cleaning trade had been but small and local. As far as was known there had been no direct trade contacts between that firm and London. An indication as to the possible origin of the species was found, however, in a few bags of stained blanched-almond pickings hidden away in a neglected corner. They were also attacked and an enquiry revealed that they were a sample bought from one of the larger Liverpool almond millers in 1947 when, due to the shortage of suitable material, it had been thought that they would make parrot food. This was not the case and they remained unused. As was anticipated it was subsequently found that the almond mill concerned was one of those having a heavy *Aphomia* population.

So far, in the north-west, all but three of the known premises where this species has been found are partly or wholly heated. Two of these were the warehouses already mentioned. In the one, control was obtained by the immediate treatment of the infested parcel of goods, though in the other a single generation was completed before insecticidal measures and the removal of infestable goods resulted in its eradication. The third was also a Liverpool warehouse where in October 1954 a larval migration occurred from Australian sultanas stored there for the previous two years. These goods had been fumigated before storage and the evidence in the form of old cocoons pointed to the infestation having been acquired from insects established in the warehouse. Though not yet confirmed, these insects had probably been introduced early in 1953 on apricot kernels.

From Scotland only two records are known. One larva was found in November 1952 in the nut-storage room of a chocolate manufacturer in Dundee and two male moths were found on a general food warehouse in Glasgow in August 1954. The origin of these specimens is not apparent though in the latter case the fact that there is a slight traffic of goods between the affected premises and the warehouses owned by the same firm in Liverpool suggests a possible source.

The present known distribution of this species in Britain is thus irregular. The findings of the survey made to determine its status in the north-west would, however, suggest that there is every possibility of it becoming established, if it

has not already done so, in suitable premises such as almond mills, nut-processing and confectionery factories in other parts of the country.

Discussion.

It would appear from its world distribution (fig. 1) that *Aphomia gularis* is a subtropical and warm-temperate species, being rarely found in the tropics and only able to maintain itself towards the northerly limits of its range, as in northern Britain and Sweden, in the store rooms of heated factories. Where its range spreads to the tropics it is confined to either high or relatively dry regions, its ecological niche being occupied elsewhere by the very closely related *Corcyra cephalonica* (Stnt.), a species with which it has only once been recorded and that as a pest of grain in the southern interior of California (Linsley & Michelbacher, 1943). In the cooler temperate regions such as Britain, while winter temperatures in unheated premises do not appear to affect survival, the summer temperatures would not seem sufficiently high to enable it to multiply quickly enough to compete with such species as *Ephestia elutella* (Hb.) which occupy much the same niche there. The fact that it has disappeared from warehouses when these ceased to handle nuts would indicate that under certain conditions it is also severely limited by its food requirements.

The absence of records of a more general distribution from elsewhere in the world is surprising and especially so from countries in the southern hemisphere where conditions would appear to be suitable. It may be that its presence has not been recognised or, on the other hand, it may not yet have been carried to those countries either because there is no trade in infestable goods between them and those where it is established or, where such trade does exist, the conditions of carriage may be such that the insect cannot survive them.

Further work is necessary on the limiting conditions of temperature and humidity for this species so that the kind of climate in which it can successfully increase may be indicated. When this has been done, careful surveys need to be made in appropriate countries and, if the species is not found, quarantine measures against introduction might be desirable. Where the pest is already established, rigorous control measures should be taken to endeavour to stamp out the pockets of infestation and so prevent further dispersal.

Summary.

A summary is made of the literature dealing with the bionomics of *Aphomia gularis* (Zell.), a storage pest of almonds, walnuts, groundnuts and prunes, and to a lesser extent of rice and grain. Additional information is also given on its habits and occurrence in Britain.

An outline is given of its origins, introduction and establishment in various parts of the world. The evidence leaves little doubt that the species originated in south-east Asia, its occurrence elsewhere being, with few exceptions, confined to the major ports of western Europe and North America. Cases of the spread of the pest from south-east Asia can be traced to the export of infested goods from that area. Unless action is taken to prevent further dispersal and measures applied to wipe out the known centres of infestation, further establishment of this species can be expected in countries at present not affected.

It would appear that *A. gularis* is a subtropical and warm-temperate species, rarely found in the tropics and only able to maintain itself towards the northerly limits of its range, as in northern Britain and Sweden, in heated premises. In the cooler temperate regions, such as Britain, it cannot compete with such species as *Ephestia elutella* (Hb.) while in the tropics its ecological niche is filled by the very closely related species *Corcyra cephalonica* (Stnt.).

Its apparent absence from regions in the southern hemisphere, where conditions favourable for development exist, may be due to its presence not having yet been recognised.

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References.

- ANON. (1934). Insect pests of dried fruits.—Mon. Bull. Calif. Dep. Agric., **23**, pp. 204–206.
- ANON. (1938). Plant pathology and entomology.—Misc. Publ. nat. agric. Res. Bur. China, no. 7 (Rep. 1936), pp. 46–52.
- ANON. (1953). The protection of foodstuffs in store. Report of the Stored Products Working Party. . . .—42 pp. Paris, Europ. Plant Prot. Org.
- ANON. (1956). Plant quarantine announcements. Egypt.—FAO Plant Prot. Bull., **4**, p. 111.
- AMSEL, H. G. (1937). Bemerkungen über den Samenzünsler *Paralipsa gularis* Z.—Anz. Schädlingsk., **13**, pp. 85–87.
- ANDER, K. (1951). *Paralipsa gularis* Zell. (Lep. Pyr.), en för Sverige ny förråds-skadeinsekt.—Opusc ent., **16**, p. 64.
- BEIRNE, B. P. (1952). British Pyralid and plume moths.—Wayside & Woodland Ser., 208 pp. London, Warne.
- BRIEJÈR, C. J. (1939). Methallyl chloride as a fumigant against insects infesting stored products.—101 pp. Amsterdam, N.V. de Bataafsche Petrol. Maatsch. Lab.
- BUTLER, A. G. (1879). Illustrations of typical specimens of Lepidoptera Heterocera in the British Museum. Pt. III.—82 pp.
- CARADJA, A. & MEYRICK, E. (1935). Materialien zu einer Microlepidopteren-Fauna der chinesischen Provinzen Kiangsu, Chekiang und Hunan.—96 pp. Berlin, Friedländer.
- CORBET, A. S. & TAMS, W. H. T. (1943). Keys for the identification of the Lepidoptera infesting stored products.—Proc. zool. Soc., (B) **113**, pp. 55–148.
- DE ONG, E. R. (1919). An imported feeder on stored peanuts.—J. econ. Ent., **12**, p. 407.
- DE ONG, E. R. (1923). *Habrobracon juglandis* Ashmead as a parasite of *Plodia interpunctella* Hubn.—J. econ. Ent., **16**, pp. 550–551.
- DIAKONOFF, A. & DE BOER, S. (1938). Bestrijding van schadelijke voorraadinsecten door middel van koelen.—Ber. HandMus. kolon. Inst. Amst., no. 120, 20 pp.

- DONOHUE, H. C. (1946). Notes on dried fruit insects. 1.—Pests, **14**, no. 9, pp. 32, 34.
- DONOHUE, H. C., SIMMONS, P. & BARNES, D. F. (1938). *Aphomia gularis* Zeller as a pest of prunes.—J. econ. Ent., **31**, p. 318.
- EHRHORN, E. M. (1915a). Division of Entomology.—Rep. Bd Agric. For. Hawaii, 1912-14, pp. 103-142.
- EHRHORN, E. M. (1915b). Division of Entomology.—Hawaii. For. Agric., **12**, pp. 333-336.
- EHRHORN, E. M. (1916a). Division of Plant Inspection.—Hawaii. For. Agric., **13**, pp. 341-343.
- EHRHORN, E. M. (1916b). Division of Plant Inspection.—Hawaii. For. Agric., **13**, pp. 399-400.
- EHRHORN, E. M. (1917). Division of Plant Inspection.—Hawaii. For. Agric., **14**, pp. 212-216.
- EHRHORN, E. M. (1918). Division of Plant Inspection.—Hawaii. For. Agric., **15**, pp. 207-209.
- ESSIG, E. O. (1921). Some interesting economic insects recently observed in California.—Mon. Bull. Calif. Dep. Agric., **10**, pp. 140-143.
- FORD, L. T. (1949). A guide to the smaller British Lepidoptera.—230 pp. London, S. Lond. ent. nat. Hist. Soc.
- FREEMAN, J. A. (1948). World foci of infestation and principal channels of dissemination to other points, with suggestions for detection and standards of inspection.—FAO agric. Stud., no. 2, pp. 15-34. Washington, D.C.
- FREEMAN, J. A. (1950). Methods of spread of stored products insects and origin of infestation in stored products.—Proc. 8th int. Congr. Ent., pp. 815-825.
- GRAY, H. E. (1953). A cereal moth (*Aphomia gularis* Zell.).—Canad. Ins. Pest Rev., **31**, p. 249.
- HAMPSON, Sir G. F. (1898). The moths of India. Supplementary paper to the volumes in "The fauna of British India". Pt. IV.—J. Bombay nat. Hist. Soc., **12**, pp. 73-98.
- HAMPSON, Sir G. F. (1917). A classification of the Pyralidae subfamily Gallerianae.—Novit. zool., **24**, pp. 17-58.
- HAYHURST, H. (1940). Insect pests in stored products.—83 pp. London, Chapman & Hall.
- HINTON, H. E. (1943). The larvae of the Lepidoptera associated with stored products.—Bull. ent. Res., **34**, pp. 163-212.
- HINTON, H. E. & CORBET, A. S. (1949). Common insect pests of stored food products. A guide to their identification.—Econ. Ser. Brit. Mus. (nat. Hist.), no. 15, 2nd edn., 52 pp.
- HOFMANN, E. (1910). Die Schmetterlinge Europas, **2**, p. 494.
- HSIU (Chu-sieh). (1936). The interrelation of self-heating of stored grain and granary pests. [In Chinese.]—Ent. & Phytopath., **4**, pp. 80-83.
- JACOBS, S. N. A. (1933). *Aphomia gularis* (Zell.) and other rare warehouse moths.—Entomologist, **66**, p. 195.
- JACOBS, S. N. A. [1935]. *Aphomia gularis*, Zell.—Proc. S. Lond. ent. nat. Hist. Soc., 1934-35, pp. 99-104.

- JENNER, J. H. A. (1892). *Melissoblastes gularis*, Zeller, a new granary pest.—Entomologist, **25**, p. 286.
- DE JOANNIS, J. (1908). *Paralipsa gularis* Zeller. Gallériide d'origine orientale observée récemment en France (synonymie).—Bull. Mus. Hist. nat., **1908**, pp. 277–282.
- KABIS, G. (1908). *Paralipsa modesta* Butl.—Ent. Z., **22**, p. 161.
- KAWANO, T. (1939). Studies on a new method of rice storage. [*In Japanese.*]—J. agric. Sci. Tokyo Nogyo Daigaku, **1**, pp. 101–140.
- KEMPER, H. (1939). Die Nahrungs- und Genussmittelschädlinge und ihre Bekämpfung.—Hyg. Zool., **6**, 270 pp. Leipzig, Schöps.
- KONO, T. (1940). Experiments with fumigation with chloropicrin against insect pests of stored grain. [*In Japanese.*]—J. Plant Prot., **27**, pp. 276–283.
- LAING, F. (1922). An eastern species of Galleridae imported into Britain.—Ent. mon. Mag., **58**, p. 191.
- LEHMENSICK, R. & LIEBERS, R. (1937). Die Oberflächenstruktur von Motteneiern als Bestimmungsmerkmal.—Z. angew. Ent., **24**, pp. 436–447.
- LE MARCHAND, S. (1928). *Paralipsa gularis* Zeller à Bordeaux (Lep. Galleriidae).—Bull. Soc. ent. Fr., **1928**, pp. 307–308.
- LHOMME, L. (1935). *Paralipsa gularis* Zeller.—Cat. Lepid. Fr. Belg., **2**, p. 162.
- LIEBERS, R. (1937). *Aphomia gularis* Zeller in einer rheinischen Süßwarenfabrik.—Anz. Schädlingsk., **13**, pp. 7–11.
- LINSLEY, E. G. & MICHELBACHER, A. E. (1943). A report on insect infestation of stored grain in California.—J. econ. Ent., **36**, pp. 829–831.
- DE LOVERDO, J. (1907). L'action des basses températures sur les oeufs et les chenilles de *Paralipsa gularis* Zeller.—C. R. Acad. Sci., Paris, **145**, pp. 90–92.
- MACKIE, D. B. (1942). Bureau of Entomology and Plant Quarantine.—Bull. Calif. Dep. Agric., **30**, pp. 337–373.
- MACNAY, C. G. (1952a). A Pyralid, n. rec. (*Aphomia gularis* Zell.).—Canad. Ins. Pest Rev., **30**, p. 266.
- MACNAY, C. G. (1952b). A Pyralid (*Aphomia gularis* Zell.).—Canad. Ins. Pest Rev., **30**, p. 281.
- MACNAY, C. G. (1953). Outbreaks and new records. Canada.—FAO Plant Prot. Bull., **2**, pp. 43–44.
- MÜLLER, H. (1939). Der Samenzünsler *Paralipsa* (*Aphomia*) *gularis* Zeller und seine Bekämpfung.—Anz. Schädlingsk., **15**, pp. 51–56.
- MUNRO, J. W. (1940). Report on a survey of the infestation of grain by insects.—54 pp. London, Dep. sci. industr. Res.
- RAGONOT, E. L. (1901). Monographie des Phycitinae et des Galleriinae.—Mém. Lépid., **8**, 602 pp.
- RICHARDS, O. W. (1931). *Aphomia* (*Paralipsa*) *gularis* Zeller (Galleriidae).—Ent. mon. Mag., **67**, p. 59.
- RICHARDS, O. W. & HERFORD, G. V. B. (1930). Insects found associated with cacao, spices and dried fruits in London warehouses.—Ann. appl. Biol., **17**, pp. 367–395.
- RICHARDS, O. W. & WALOFF, N. (1947). Seasonal variations in the number of some warehouse insects.—Proc. R. ent. Soc. Lond., (A) **22**, pp. 30–33.

- SHIBUYA, M. & YAMASHITA, S. (1936). Studies on the utilisation of a Hymenopterous parasite of the Rice Borer introduced from the Philippines. [*In Japanese.*]—Nojikairyo-Chiryō, no. 116, 41 pp.
- SILVESTRI, F. (1951). Compendio di entomologia applicata. Vol. 2 parte 2. Lepidoptera.—Boll. Lab. Ent. agr. Portici, **10**, pp. 131–303.
- STEINHAUS, E. A. (1951). Possible use of *Bacillus thuringiensis* Berliner as an aid in the biological control of the Alfalfa Caterpillar.—Hilgardia, **20**, pp. 359–381.
- SWEZEY, O. H. (1913). Notes on two Galleriids.—Proc. Hawaii. ent. Soc., **2**, pp. 211–212.
- WAKELY, S. (1932). *Aphomia gularis* (Zeller) in London.—Entomologist, **65**, p. 229.
- WAKELY, S. (1933). *Aphomia gularis* (Zeller) in Britain.—Entomologist, **66**, p. 99.
- WEIDNER, H. (1936). Aus der Schädlingsabteilung des Zoologischen Staatstinstitutes und Zoologischen Museums, Hamburg.—Anz. Schädlingssk., **12**, pp. 13–17.
- YANG (Chio-ching). (1934). Some preliminary notes on stored grain insects of Sioshan, Chekiang, May, 1934. [*In Chinese.*]—Ent. & Phytopath., **2**, pp. 416–421.
- ZACHER, F. (1927). Die Vorrats-, Speicher- und Materialschädlinge und ihre Bekämpfung.—366 pp. Berlin, Parey.
- ZACHER, F. (1933). Ein neuer Vorratsschädling in Deutschland (*Aphomia gularis* Zell., Lep., Pyralidae.).—Mitt. Ges. Vorratsschutz, **9**, p. 11.
- ZACHER, F. (1934). Ein neuer Schädling breitet sich aus: Der Samenzünsler, *Aphomia gularis*.—Mitt. Ges. Vorratsschutz, **10**, pp. 37–39.
- ZACHER, F. (1935a). Die Vorratsschädlinge im Jahre 1934 insbesondere Kornkäfer und Samenzünsler.—Mitt. Ges. Vorratsschutz, **11**, pp. 31–38.
- ZACHER, F. (1935b). Beobachtungen ueber Speichereinsekten.—Anz. Schädlingssk., **11**, pp. 63–66.
- ZACHER, F. (1939a). Der Samenzünsler jetzt auch in Berlin.—Mitt. Ges. Vorratsschutz, **15**, pp. 20–21.
- ZACHER, F. (1939b). Verschleppung und Einbürgerung von Vorratsschädlingen.—Verh. 7. int. Kongr. Ent., **4**, pp. 2919–2926.
- ZACHER, F. (1941). Beobachtungen über “Kornmotten”.—Z. angew. Ent., **28**, pp. 466–476.
- ZELLER, P. C. (1877). Exotische Microlepidoptera.—Horae Soc. ent. ross., **13**, pp. 3–495.
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FIG. 1. *Aphomia gularis* Zell. Female (left), male (right). ($\times 5$).



FIG. 2. Almonds showing damage and contamination resulting from attack by larvae of *Aphomia gularis*.

CATCHES IN THE GAMBIA, WEST AFRICA, OF *ANOPHELES GAMBIAE* GILES AND *A. GAMBIAE* VAR. *MELAS* THEOBALD
IN ENTRANCE TRAPS OF A BAITED PORTABLE WOODEN
HUT, WITH SPECIAL REFERENCE TO THE EFFECT
OF WIND DIRECTION.

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(PLATE XIII.)

McGregor & Smith (1952) reported in their survey of the health of the inhabitants of the village of Keneba in the West Kiang district of the Gambian Protectorate that, owing to their high density in the wet season, *Anopheles gambiae* Giles and *A. gambiae* var. *melas* Theo. were the dominant vectors of malaria and filariasis. In the investigations which have continued in this locality since then, much attention has been paid to the possibility of controlling these mosquitos. Assessment of the efficiency of control methods has demanded fairly detailed knowledge of local mosquito biology and behaviour. Of particular importance has been the measurement and explanation of fluctuations in the numbers of mosquitos found resting in village houses, and much information on this subject has been provided by routine indoor collections using sucking-tubes, both with and without previous space-spraying with insecticide. The data thus collected clearly indicates that many variable factors exerted considerable influence on the density of resting mosquitos and that some of the variation arose from differences in the design, materials, state of repair and usage of the village houses in which catches were made. To secure reasonable accuracy in the assessment of control efficiency, elimination of as many of these variables as possible was imperative, and, accordingly, standard experimental mud huts conforming to the local pattern of village houses were built and used as catching houses.

Experimental huts of this type have in recent times yielded valuable information on mosquitos and their reaction to residual insecticides (Muirhead-Thomson, 1951; Macdonald & Davidson, 1953). The general features of such huts follow those developed in East Africa by Muirhead-Thomson (1945), although other workers have since introduced modifications suited to their own problems (Wharton, 1951; Wilkinson, 1951; and Gillies, 1953). In the use of these huts, mosquitos are collected indoors by the usual methods, but this catch is supplemented by fitting a trap to the window (usually one) so that mosquitos leaving the hut by that route are captured. Mosquitos flying to escape by the window enter a cone of netting pointing outward and, passing through a small hole in the apex, become confined in a cage of mosquito netting into which the cone protrudes. The entry of mosquitos to some models of hut is by adventitious small gaps in the structure or, in other types, by the considerable space around

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the eaves; more elaborate arrangements have been provided to suit special requirements.

Unfortunately, in the work in West Kiang, the experimental mud huts of village pattern fitted with exit traps have, so far, given disappointing results. As a result of this experience, we turned again to an idea which had long seemed suited to some at least of our field problems. We supposed, in the first place, that measures of density and certain other aspects of the biology and behaviour of *A. gambiae* and its variety *melas* might be determined more conveniently, and at least as efficiently, by catching the mosquitos at once in traps as they entered a hut rather than later when they had entered and come to rest or had moved into an exit trap. Secondly, it seemed that with several wooden and portable huts fitted in this way, comparative sampling could be readily undertaken at any selected sites in or in the vicinity of villages, breeding places, and so on. Although there is a considerable literature describing numerous types of trap for mosquitos (see Boyd, 1949), some of them portable, little seems to have been done with huts or houses in which traps are mounted in the windows to catch the entering mosquitos. Le Prince & Orenstein (1916) used entrance traps successfully in windows of labourers' huts in Panama, the opening into the trap being a long slit of elaborate design. Later, van Thiel (1937) caught races of *A. maculipennis* Mg. in Europe in entrance traps fitted to hutches baited with man or animal, the traps having a simpler type of vertical slit as an opening. On the other hand, Simmons & others (1945) in America discontinued the use of entrance slots in windows as they appeared to restrict the inflow of mosquitos.

As an essential preliminary to developing the possibilities in mind we tried out, during August and September 1954, a portable wooden hut fitted with two traps of the same design as the exit traps now so widely used in experimental huts but placed so as to catch mosquitos as they entered the hut by the windows. No other points of entry were available. Substantial catches of up to 1,240 females of mixed populations of *A. gambiae* and the variety *melas* were taken in a night. The design of the hut also revealed that the mosquitos concentrated in the leeward trap if the wind persisted from one direction; with variable winds and, possibly, in calm conditions they occurred in both traps. The present paper describes the hut and the results obtained, discussing these from the point of view of the value of the hut as a sampling device for investigating certain aspects of mosquito biology and behaviour.

The Hut.

Design.

The hut (Pl. XIII, fig. 1) was 6 ft. 8 in. long, 4 ft. broad and 7 ft. high and constructed of plywood sheets fixed to a framework of mahogany posts and spars. An arched roof extended about 6 in. beyond the ends and sides of the hut. A window space, 14 in. square, was provided midway along each long side at 4 ft. from the ground and, at 14 in. from the ground on these sides there was also a slit opening, 4 ft. 6 in. long and one in. wide, protected outside by a sloped overlapping flange. A closely fitting door occupied about half of one end; the other end had no openings. Legs, part of the structure of the floor, kept the hut about 6 in. clear of the ground. The hut, made in the Laboratories' workshop at Fajara in six sections (roof, floor and four sides) was transported in sections by road to Keneba where it was assembled and a cover of tarred felt fixed by battens to the roof and all outer surfaces as a protection against rain. A long spar, extending 3 ft. beyond the hut at each end, was then screwed to each side of the hut 18 in. from the ground. The assembled hut was light enough to be moved short distances like a sedan chair by four men. For longer distances, up to four miles, it was loaded on its side and lashed by ropes on to a small trailer and pulled behind a vehicle along rough bush roads.

Three interchangeable fittings were made for each of the window spaces. A panel of wood slightly greater in area than a window space could be fitted to close the opening completely. A second panel, largely of metal mosquito netting, could be substituted to make the opening mosquito-proof but permit free movement of air through the window. The third fitting was again a wooden panel but a central area was cut out and fitted with a mosquito trap of the cone type used by Muirhead-Thomson (1945). The actual trap (Pl. XIII, fig. 3) was a 9-in. cube of white cloth mosquito netting except for the cone which was in dark metal mesh. One side of the trap had a wool-plugged hole in it for use when sucking out mosquitos. These fittings could be put in place quickly either from the inside or the outside of the hut. They were held firmly by swivelling stops on the hut at positions close to the corners of the panels.

Method of use.

The hut contained only a bed, bedding and a small amount of essential entomological equipment and was baited with either an African or a European. After preliminary trials the slit openings were sealed with mosquito netting and, in the observations now reported, served only as a means of additional ventilation. The traps were affixed in the windows so that the trap body projected into the hut (Pl. XIII, fig. 2). Thus, when the human bait was in occupation with the door closed, mosquitos could only enter the hut by the windows and in so doing were confined in the traps. The human bait occupied the hut for such time as was desired, usually from before dusk until after dawn when the traps were finally cleared. On the occasions when one of the authors acted as bait, periodic observations were made throughout the night and the traps cleared of mosquitos with a sucking-tube at hourly or two-hourly intervals. The human bait always remained in darkness except when using a hand torch for brief observation and periodic collection from the traps. Since active mosquitos proved difficult to catch by sucking tube, the cotton netting of the traps was sprayed just before the evening's investigations began with an aerosol containing pyrethrins and piperonyl butoxide but no residual insecticide. It was found that sufficient insecticide remained on the fabric throughout the night to immobilise all mosquitos within a few minutes of entry. No repellent action was noted in any of the experiments. The catches were kept in the hut in labelled test tubes until they could be examined and counted in the laboratory next day.

The long axis of the hut was placed in an east-west direction with the long sides bearing the window traps facing north and south. The door faced eastwards. The hut was sometimes sited in various compounds in the villages of Jali and Keneba but the observations reported in detail in this paper were obtained when the hut was placed in the more open compound of the M.R.C. Laboratory about 300 yards north-east of Keneba village. Eleven adult males, nine African and two European, acted as bait on different occasions.

Wind observations.

No instruments were available for recording wind. The simple descriptions of wind in the text are based on a combination of general appreciation, periodic observation of smoke drift outside the hut, and the physical recognition inside the hut of a current of cool air entering the hut by one or the other window and also through the corresponding screened slit opening. Usually, the wind is referred to merely as southerly or northerly, which is sufficient to express the fact that it was felt entering the hut through the south or north window, respectively. Occasionally, other directions are given. The direction of the wind is also indicated in the figures. The strength of the wind is described in general terms such as light, etc., as judged by personal observation. Wind observations are those of the author who also made the mosquito observations for the night in question.

Differentiation of A. gambiae and A. gambiae var. melas.

We have accepted the nomenclature adopted by De Meillon (1947). It is known from McGregor & Smith (1952) that both *A. gambiae* and *A. gambiae var. melas* (= *A. gambiae melas* and *A. melas* of some authors) occur abundantly at Keneba and nearby villages. These villages lie close to (at most $1\frac{1}{2}$ miles from) the saline creeks and swamps of the River Gambia or its subsidiary, the Bintang creek, with their stands of *Rhizophora* and *Avicennia* mangrove. The most reliable method of differentiating the individual females of the species and its variety depends on obtaining their eggs (Chwatt, 1945; Muirhead-Thomson, 1948). It may be assumed, if eggs are not obtained, that most of the females with 4-banded palps are of the variety and those with 3-banded palps are either *A. gambiae* or *melas*. It was not practicable to feed and keep the females of our catches until they oviposited, but the number of females with distinctly 4-banded palps was counted for most of the catches. In the text below, the percentage of females with 4-banded palps in a catch is frequently given as the best available indication that the population comprised both the species and the variety.

Results.

Night collections at hourly and two-hourly intervals.

The results, obtained during one night when one of the authors (D. S. B.) acted as bait from 1830 to 0830 hr. (G.M.T.) * except when relieved by another European for about half-an-hour before 2000 hr. are illustrated in fig. 1. Apart from a period of sleep from 0330–0400 hr., observations were maintained on both traps throughout the night and the traps were emptied of mosquitos at hourly intervals. The 0330–0400-hr. catch was discarded, and from 0400 hr. a new hourly catch was instituted.

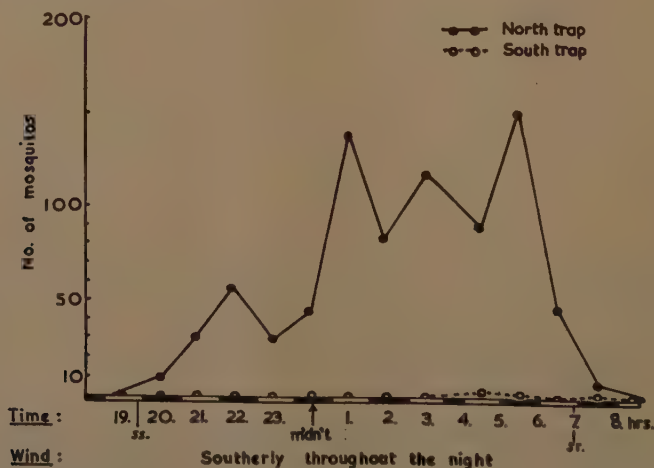


Fig. 1.—The numbers of *A. gambiae* and *A. gambiae var. melas* taken in entrance traps in one night during the catching periods and in the wind conditions shown. Time as Greenwich Mean Time. ss = sunset. sr = sunrise.

The total catch for the night was 797 females of *A. gambiae* and its melanistic variety. Of this, 791 were caught in the north trap and only six in the south one. The latter occurred as 3, 2 and 1 females in three of the hourly periods between

* Time is expressed throughout as Greenwich Mean Time, which is 1 hr. 6 min. ahead of Local Mean Time.

0400 and 0800 hr. In the north trap, the largest catches were taken in the periods 0030–0130 hr. and 0500–0600 hr.

Females with 4-banded palps constituted 30.6 per cent. of the total night's catch.

Frequent observations revealed that a light southerly wind persisted throughout the night, creating a cool distinct air current which entered the hut by the trap and the screened slit on the south wall. Thus, practically all the mosquitos attempted to enter the hut by the window on the lee side.

Both traps were frequently inspected between the times of emptying them and no mosquitos were seen to enter the windward trap and subsequently leave it nor was there evidence of any predators in this and subsequent experiments.

The results for a subsequent night when both traps were again in position are shown in fig. 2. Bait was provided first by two African technicians alternating from 2000 hr. to 2330 hr., followed until 0800 hr. by the same author who occupied the hut in the previous experiment. Mosquitos were collected from the traps at two-hourly intervals. The north trap again caught most mosquitos (160 females) with a maximum count of 68 females between 0200 and 0400 hr. In the south trap, the numbers fluctuated from *nil* in one period up to as many as 9 females in the other periods, giving a total of 26 females. The percentage of females with 4-banded palps was 16.9 per cent. of the night's catch.

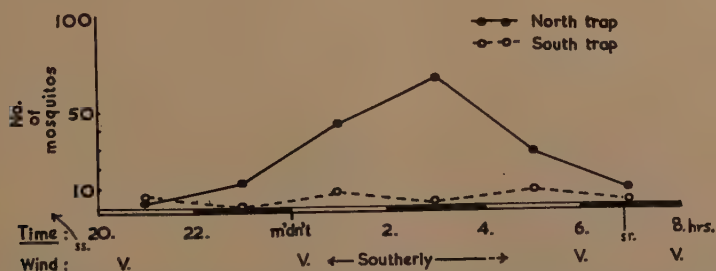


Fig. 2.—The numbers of *A. gambiae* and *A. gambiae* var. *melas* taken in entrance traps in one night during the catching periods and in the wind conditions shown. V = variable wind direction. Other symbols as fig. 1.

The wind was very light and variable, sometimes barely detectable, when observed in the early evening at 2030 hr., during the half-hour after midnight, and at 0600 and 0800 hr. in the morning. Mosquitos were found in both traps in relation to these periods of light, variable wind. More detailed observations were made of wind in relation to mosquito entries after the traps were emptied at midnight. The wind, as noted above, was very light and very changeable for the first half-hour after midnight, its direction including west, south and north besides moments of calm. Within the next 20 minutes the wind, now slightly stronger, settled in the south and, indeed, continued until at least 0400 hr. as a distinct, cool, air current entering the hut by the south trap and screened slit. Observations of the traps, without collection, shortly after this change to a settled southerly wind revealed only a few dying mosquitos in the south trap and a number of very active females in the north trap. The latter must have been very recent entries which had not been sufficiently long in touch with the insecticide on the fabric of the trap to show signs of incapacitation. At the collection at 0200 hr. the south trap contained 9 females, about the number observed dying just before 0100 hr., and there were 41 females in the north trap, most of them having entered this trap during the hour after the wind had settled to a southerly direction. The continuing southerly wind until at least 0400 hr. is related to the maximum catch of 68 females in the north trap and only one specimen in the

south trap for the period 0200–0400 hr. The differences between the traps is less marked in the two following periods at the end of which light variable air currents prevailed.

The results from about 0100 until 0400 hr. confirm those of the first experiment. The mosquitos entered mainly the north or leeward window when a distinct light wind persisted from the south. Moreover, mosquitos entered both traps during periods when very light, fluctuating winds with moments of stillness occurred.

The results on a third occasion are illustrated in fig. 3. An African technician acted as bait from 1900–2400 hr. when he was replaced, until 0700 hr., by one of the authors. The traps were emptied at hourly intervals except for an unintentional period of sleep from 0400–0600 hr. The total catch for the night was 1,240 females of *A. gambiae* and its variety, of which 978 were in the south trap and only 262 in the north trap, although this trap was in use for five hours longer than the south trap. There were 19.3 per cent. of females with 4-banded palps in a sample of 426 examined.

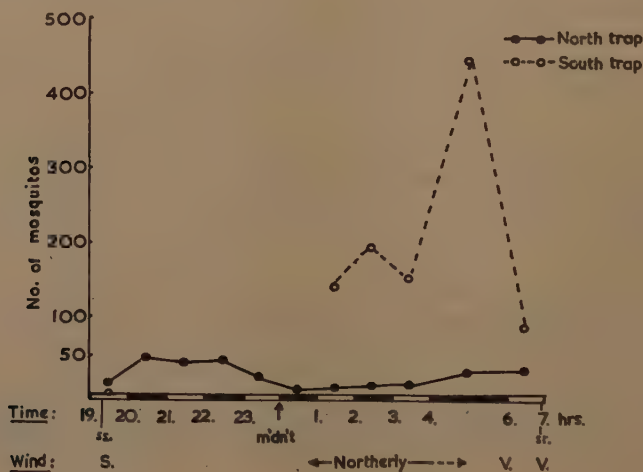


Fig. 3.—The numbers of *A. gambiae* and *A. gambiae* var. *melas* taken in entrance traps in one night during the catching periods and in the wind conditions shown. S = southerly wind. Other symbols as figs. 1 and 2.

The small catch of 14 females during the first period from 1900 to 2000 hr. was entirely in the north trap which, in view of a light southerly wind, was again the leeward trap. Assuming that the south trap would not catch much, if anything at all, it was replaced by a panel of metal netting. During the next three hours the numbers of mosquitos entering the north trap remained fairly stable between 40 and 50 per hour. The catch for the hour up to midnight was, however, only 23 mosquitos. Shortly after the change of human bait at midnight, it was noticed that mosquitos were humming outside the gauze panel in the south window and several could be seen alighting on it. A check of the wind showed that a distinct, light wind was now causing a cool current of air to enter the hut through the north trap and screened slit. By the time of the collection at 0100 hr. only five females had entered the north trap. It seemed now likely that the south trap would catch the mosquitos and so it was put back in place in the south window. The graph shows clearly the result. Substantial numbers of mosquitos entered the south trap for the remaining periods of the night while the entries to the north trap continued low although they increased later to about

30 per period. At frequent checks from 0100 hr. to 0400 hr. a northerly wind was detected, but it is not known when this wind changed to the very light, variable wind observed at 0600 hr. and, again, at 0700 hr.

The catches for this night again demonstrate a considerable concentration of mosquitos into the leeward trap, which, in this case, was mainly the south trap in view of the northerly wind, at least from just after midnight until 0400 hr., and probably for some time after that. Just before dawn, mosquitos occurred in both traps in reasonable numbers; two observations of the wind indicated that very variable winds prevailed for some part of this period.

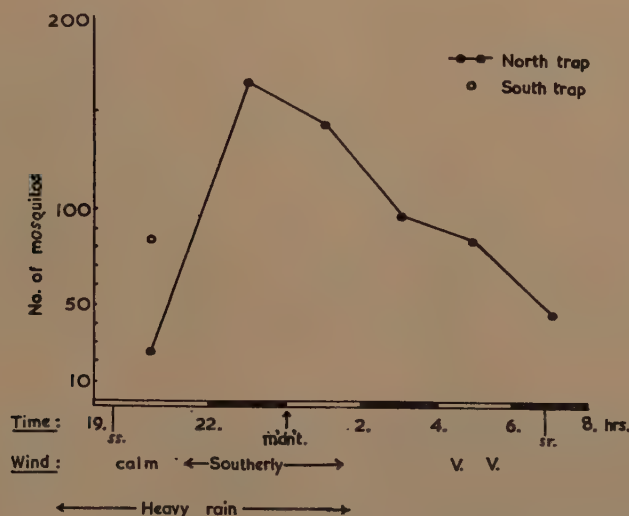


Fig. 4.—The numbers of *A. gambiae* and *A. gambiae* var. *melas* taken in entrance traps (mainly north trap only) in one night during the catching periods and in the weather conditions shown. Symbols as figs. 1 and 2.

The results of one of the earliest trials of the hut are shown in fig. 4. An African villager occupied it from 1900 hr. to 0800 hr. Both traps were in position until the first collection was made at 2200 hr. Just before this collection, heavy rain, which had fallen vertically since 1800 hr., began to be blown into the hut through the south trap by a southerly wind. The south trap was therefore replaced at 2200 hr. by a solid wooden panel. This window remained completely closed for the rest of the night, although any southerly air current could still enter the hut by the screened slit on the south side. For the rest of the night one of the authors made two-hourly observations of the north trap by interchanging traps in the north window and examining the catch at once in the laboratory. The total catch for the night was 741 females of *A. gambiae* and the variety *melas* of which 82 were taken in the south trap in the single three-hour period up to 2000 hr. when both traps were in position. The catch for this period in the north trap was 23 females. Mosquitos were observed in both traps while the rain was falling vertically and conditions were calm. The graph shows clearly that substantial numbers of mosquitos entered the north trap in the period ending at midnight but that the numbers then declined steadily until dawn. Females with 4-banded palps comprised 25.5 per cent. of the catch for the night.

The rain stopped just before 0200 hr. and was followed by dry weather apart from occasional light rain for brief periods until after dawn. The southerly wind

which had begun to blow just before 2200 hr. continued until at least 0145 hr. but, after this time, no more wind observations were made until 0430 hr. and again at 0530 hr. when the wind was on both occasions very light and variable from south-west to east. These results show that considerable numbers of *A. gambiae* and *melas* were in flight and entering the hut during about seven hours of heavy rain. At the beginning of the evening they entered both traps when rain was falling vertically and conditions were apparently calm. The graph shows a continuous decline in activity in the latter half of the night after the heavy rain stopped.

Different sizes of night catch.

It will be noticed that the total catch of mosquitos on one of the nights discussed above was only 186, a low figure in comparison with 797, 741 and 1,240 females for each of the other three nights. These three large catches, together with two others of 642 females and 1,110 females on nights when only one trap was in position, were taken between 24th August and 1st September at the M.R.C. compound near Keneba. The low catch of 186 females, also at this compound, was one of 13 subsequent night catches between 6th and 22nd September, of which five were at the M.R.C. compound and four in each of the villages of Keneba and Jali. Both traps were in position during all these nights. The total catch per night in this series ranged from 27 to 306 females, even if we exclude the results in the village compound at Keneba which had been treated with dieldrin about two months previously. Thus, a period of high catches was followed by a series of low catches.

Other observations.

During the period of these observations sunset was between 1923 and 1902 hr., and sunrise between 0654 and 0655 hr. *A. gambiae*, or its variety *melas*, first entered the traps a little before darkness was complete in the evenings and continued to come in until morning light after sunrise was appreciable. The first and last noted entries were, respectively, 1935 hr. and 0728 hr.

In the 18 nights of trapping between 24th August and 22nd September the total catch in the traps of *A. gambiae* and its variety was 5,901 females, all of them unfed except two specimens which had a partial, fresh blood-meal. None showed advanced signs of gravidity externally and a small number dissected had ovaries at stage II or earlier. No males were taken in the traps.

Of other Anophelines, only a single female of *A. funestus* Giles and one of *A. rufipes* var. *ingrami* Edw. were taken at Jali and the M.R.C. compound near Keneba, respectively. The remaining mosquitos comprised 59 females of *Tacniorhynchus* (*Mansonioides*) spp., 30 of *Culex nebulosus* Theo., 19 of *C. thalassius* Theo., and 15 of unidentified species. Some *Culicoides* occurred in the traps and inside the hut itself. The numbers of the species other than *A. gambiae* and its variety *melas* are so small that they are not considered in the discussion which follows.

Discussion and Conclusions.

Boyd (1949) in his book (p. 659) remarks that a good deal of Anopheline movement is probably up-wind towards hosts in response to attractive stimuli borne from them down-wind. Our results during periods of sustained wind, when *A. gambiae* and its variety *melas* entered the baited hut only by the leeward trap, support this view, particularly as no mosquitos entered the traps in the absence of the bait, even with a wind blowing. Earlier workers have noted this concentration of mosquitos into a leeward trap, attributing it to attractive emanations from the host being carried down-wind. Thus, Le Prince &

Orenstein (1916) state that "*Anopheles*" always entered window traps on the lee side of labourers' houses in Panama although "*Culex*", curiously, were more often taken in leeward traps. Van Thiel (1937) in Europe always sited his window traps to leeward on the basis of this earlier observation and in a single night's test, using *A. maculipennis atroparvus* van Thiel, found 77 females in the leeward trap and two in the windward trap of a baited hut. And in South Africa, De Meillon (1935), using a fan as a source of wind, collected in one night 60 females of *A. funestus* from the leeward and none from the windward side of a baited, screened tent. These records although few and meagre are, at least for Anopheline mosquitos, consistent with our findings and it is of interest that they concern other species of *Anopheles*.

The present experiments do not reveal what the attractiveness of a bait may be but this is a subject which has received attention from other workers. Most recently, in field work with a robot, Brown (1951) concluded that moisture, warmth, carbon dioxide, and sweat contributed to the attraction of forest species of *Aedes* in Canada. Van Thiel (*loc. cit.*) considered odour important in the differentiation of hosts by races of *A. maculipennis*, and De Meillon (*loc. cit.*) concluded that smell attracted *A. funestus* to man. Kennedy (1940), discussing the mechanism of host-finding by mosquitos on the basis of laboratory work with the diurnal species, *Aedes aegypti* (L.), suggested that a scent in a wind probably only activates the insect to fly and that up-wind flight is then, at least in low-flying mosquitos of this species, a response to a visual perception of changes in the ground pattern beneath the mosquito. It is difficult to concede that the up-wind flight of the Anophelines in our experiments was controlled by a visual mechanism since a great part of the catches occurred during hours of darkness.

We conclude from our observations that smell and other airborne products of the host were dispersed by wind from the hut through the leeward window, creating only on this side of the hut the stimulus of attraction which directed the mosquitos into the hut. As a result, the mosquitos concentrated exclusively in the leeward trap when the wind persisted from one direction. There appear to be two possible explanations to account for mosquitos occurring in both traps at the end of a catching period. First, when changes of wind direction of sufficient arc caused alternations in the window from which attractive stimuli were dispersed, entry of mosquitos changed correspondingly from one trap to the other. Secondly, in calm conditions such as during the heavy vertical rain that we experienced, mosquitos may have entered both traps simultaneously in response to attractive stimuli diffusing more or less equally through both windows at the same time. However, without continuous recordings of wind it is difficult to be certain of the latter mechanism as very brief moments of wind from opposite directions during otherwise calm conditions might well, by the first method, result in mosquitos being found in both traps after a period of time.

It follows from these conclusions that if only one trap is available to the mosquitos for entry into a hut of the kind used, serious sampling deficiencies could result from changes in wind direction. This is particularly clear from the third experiment (fig. 3). Both traps must be in position and, indeed, it is probably important to modify the present design of the hut so that there is a window trap in each of the four walls. The fourth experiment showed that *A. gambiae* and its variety *melas* are actively in flight in substantial numbers during heavy rain. As a case in point, however, we do not know, since only one trap was in use and wind observations were inadequate, whether the continuing decline in the catches after the rain ceased was due to a change of wind or some other feature of the change in weather.

As regards the size of the catch for different intervals during the night, the first experiment, in which wind direction was stable, provided a curve resembling

generally the biting-cycle determined, under different conditions and by different methods, for *A. gambiae* and var. *melas* in Sierra Leone and Nigeria by Muirhead-Thomson (1945; 1948), in Nigeria by Mattingly (1949), and for *A. gambiae* in East Africa by Haddow, Gillett & Highton (1947). All but two of the mosquitos were unfed, and the ovaries in a sample examined were at a very early stage of development. The curve probably represents the cycle of biting-activity. Although the first, second and fourth peaks of fig. 1 suggest some resemblance, although delayed, to the three main periods of entry and aggressiveness of *A. gambiae* in French West Africa (Holstein, 1954), or, the first might correspond to the initial small wave of biting females observed on tree platforms in Uganda (Lumsden, 1952), comment of this kind is permissible only as an indication of a possible use of the hut in further work. A curve for a single night is obviously insufficient data for considering detail of this kind.

Turning now to the total catches per night which consist of a series of high catches followed by a series of low catches: the explanation of the low catches could be merely that the wind direction during these nights was unsuitable for attracting large numbers of mosquitos into traps facing only northward and southward. On the other hand, an effect of this kind consistently over thirteen successive catches seems unlikely and we know that on one of these nights (fig. 2) a low catch of 186 females was taken although a southerly wind persisted for at least four hours. This doubt, however, emphasises the advisability of fitting a trap to each of the four faces of a hut of this kind. We may, however, usefully consider whether other factors exist which may have caused the sequence of low catches following a series of high ones. It is of interest to note first that, in the work on *A. funestus* in the Gold Coast (Ribbands, 1946), the largest night catches happened to occur about full moon, whereas in our series the low catches were by contrast taken in the full moon period, 13th to 20th September. The evidence of an effect of moonlight on the activity of *A. funestus* was not derived, however, from broad associations of this kind but from an analysis, for a long series of nights of timed catches throughout the night in relation to moonlit and moonless periods. Agreeing with Ribbands that an association of a cycle of high and low catches with lunar phases may well be an incidental effect of other factors controlling mosquito density, the contrast of *A. funestus* being most numerous on moonlight nights but *A. gambiae* and var. *melas*, conversely, on dark nights, is not acceptable evidence that the catches of *A. gambiae* and its variety *melas* are greater because they are more active in the dark than in moonlight. As regards other factors, it is well known that rainfall affects the numbers of *A. gambiae*; and it is clear from the work of Muirhead-Thomson (1945) and Ribbands (1944) in Sierra Leone that peaks in the density of the brackish-water breeding variety *melas* are controlled by the fortnightly, or monthly, high spring tides associated with lunar phases. The relationship may, however, be obscured in the rainy season. But, apart from possible natural causes, it may be that our catches were affected by the nearby laboratory lights at the M.R.C. compound. These, although usually put off before midnight, may have attracted more mosquitos in the darkness of more or less moonless nights than in the natural bright light of full moon with, as a result, high and low catches, respectively.

We cannot differentiate between these several factors from our present limited observations but it seems justifiable to conclude that the different sizes of night catch taken with the hut cannot be lightly dismissed as evidence of its erratic functioning as a trapping device. The trial of the hut suggests rather its suitability, particularly if fitted with a window trap in each wall, as a simple and convenient device for measuring changes in density of a mosquito population and for investigating certain aspects of mosquito behaviour, provided the indoor activity of the mosquito is not in question. In its present design, the hut has the disadvantage of not being of materials typical of African village huts but this need

not be important; a cowl over each window to keep out rain would be a useful modification.

Summary.

A portable wooden hut with two windows, on opposite sides, fitted with traps to catch mosquitos as they entered the hut was tried, with human bait, as a sampling device for mixed populations of *Anopheles gambiae* Giles and *A. gambiae* var. *melas* Theo. in and near Keneba village in the West Kiang district of the Gambia.

In eighteen night catches, between 24th August and 22nd September 1954, 5,901 females of this species and its variety were taken in the traps, five high catches (642 to 1,240 females) being made before 3rd September and thirteen low catches (27 to 306 females) between 6th and 22nd September. Possible causes for the different size of catches in the two periods are discussed with the conclusion that the differences in catch are not simply attributable to erratic functioning of the hut as a trap.

Four night catches of 186, 741, 797 and 1,240 females of *A. gambiae* and its variety are reported in detail. They reveal that mosquitos were taken virtually exclusively in the leeward trap if the wind persisted from one direction. But if the wind was variable, or conditions were calm, they were taken in both traps, entering the traps alternately as the wind shifted in the first instance and, perhaps simultaneously in calm. The results show that the use of only one trap could give misleading information about the numbers of mosquitos available outside the hut.

There is no doubt that, with wind, the mosquitos approached the host in the hut from down-wind. Since much of the catching occurred in darkness it would seem that the mosquitos were attracted by the emanations of the host and that their approach to the hut was not directed by a visual mechanism controlling up-wind flight.

Heavy rain for about seven hours did not prevent flight.

From hourly collections, made from dusk to dawn, a curve of activity for *A. gambiae* with its variety *melas* was obtained resembling the biting cycle reported elsewhere by other authors, the greatest activity occurring between midnight and 0600 hr. All the females (except two instances of incomplete fresh blood-meals) were unfed and, in a small sample, ovarian development was stage II or earlier. First entries occurred just before complete darkness in the evening and the last in good light about 30 minutes after sunrise.

No males of *A. gambiae* or var. *melas* were taken in the traps.

The numbers, all females, of other species taken were: 1 of *A. funestus* Giles, 1 of *A. rufipes* var. *ingrami* Edw., 59 of *Taeniorhynchus* (*Mansonioides*) spp., 30 of *Culex nebulosus* Theo., 19 of *C. thalassius* Theo., and 15 of unidentified species. Some *Culicoides* occurred in the traps and in the hut itself.

The hut, if modified to include a window trap in each of the four walls and a cowl over each window to keep out rain, appears to be a simple and convenient sampling device for certain types of investigations on the biology and behaviour of *A. gambiae* and its variety *melas*.

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References.

- BOYD, M. F. Ed. (1949). *Malaria*, 1, 787 pp. Philadelphia, Pa., Saunders.
- BROWN, A. W. A. (1951). Studies of the responses of the female *Aedes* mosquito. Part IV. Field experiments on Canadian species.—Bull. ent. Res., **42**, pp. 575–582.
- CHWATT, L. J. (1945). Studies on the melanic variety of *Anopheles gambiae* in southern Nigeria.—J. trop. Med. Hyg., **48**, pp. 22–30, 51–55.
- DE MEILLON, B. (1935). Studies on insects of medical importance in South Africa. (Part II.) *Anopheles funestus* Giles in relation to its host.—Publ. S. Afr. Inst. med. Res., no. 35, pp. 358–368.
- DE MEILLON, B. (1947). The Anophelini of the Ethiopian geographical region.—Publ. S. Afr. Inst. med. Res., no. 49, 272 pp.
- GILLIES, M. T. (1953). The duration of the gonotrophic cycle in *Anopheles gambiae* and *Anopheles funestus*, with a note on the efficiency of hand catching.—E. Afr. med. J., **30**, pp. 129–135.
- HADDOW, A. J., GILLET, J. D. & HIGHTON, R. B. (1947). The mosquitoes of Bwamba County, Uganda. V. The vertical distribution and biting-cycle of mosquitoes in rain-forest, with further observations on microclimate.—Bull. ent. Res., **37**, pp. 301–330.
- HOLSTEIN, M. H. (1954). Biology of *Anopheles gambiae*. Research in French West Africa.—Monogr. Ser. World Hlth Org., no. 9 (English edn.), 172 pp.
- KENNEDY, J. S. (1940). The visual responses of flying mosquitoes.—Proc. zool. Soc. Lond., (A) **109**, pp. 221–242.
- LE PRINCE, J. A. & ORENSTEIN, A. J. (1916). Mosquito control in Panama.—335 pp. New York, Putnam.
- LUMSDEN, W. H. R. (1952). The crepuscular biting activity of insects in the forest canopy in Bwamba, Uganda. A study in relation to the sylvan epidemiology of yellow fever.—Bull. ent. Res., **42**, pp. 721–760.
- MACDONALD, G. & DAVIDSON, G. (1953). Dose and cycle of insecticide applications in the control of malaria.—Bull. World Hlth Org., **9**, pp. 785–812.
- MATTINGLY, P. F. (1949). Studies on West African forest mosquitos. Part I. The seasonal distribution, biting cycle and vertical distribution of four of the principal species.—Bull. ent. Res., **40**, pp. 149–168.
- MCGREGOR, I. A. & SMITH, D. A. (1952). A health, nutrition and parasitological survey in a rural village (Keneba) in West Kiang, Gambia.—Trans. R. Soc. trop. Med. Hyg., **46**, pp. 403–427.
- MUIRHEAD-THOMSON, R. C. (1945). Studies on the breeding places and control of *Anopheles gambiae* and *A. gambiae* var. *melas* in coastal districts of Sierra Leone.—Bull. ent. Res., **36**, pp. 185–252.
- MUIRHEAD-THOMSON, R. C. (1948). Studies on *Anopheles gambiae* and *A. melas* in and around Lagos.—Bull. ent. Res., **38**, pp. 527–558.
- MUIRHEAD-THOMSON, R. C. (1951). Mosquito behaviour in relation to malaria transmission and control in the tropics.—219 pp. London, Arnold.
- RIBBANDS, C. R. (1944). The influence of rainfall, tides and periodic fluctuations on a population of *Anopheles melas*, Theo.—Bull. ent. Res., **35**, pp. 271–295.
- RIBBANDS, C. R. (1946). Moonlight and house-haunting habits of female Anophelines in West Africa.—Bull. ent. Res., **36**, pp. 395–417.

- SIMMONS, S. W. & others. (1945). Techniques and apparatus used in experimental studies on DDT as an insecticide for mosquitoes.—Publ. Hlth Rep., suppl. 186, pp. 3-20.
- VAN THIEL, P. (1937). Quelles sont les excitations incitant l'*Anopheles maculipennis atroparvus* à visiter et à piquer l'homme ou le bétail?—Bull. Soc. Path. exot., **30**, pp. 193-203.
- WHARTON, R. H. (1951). The behaviour and mortality of *Anopheles maculatus* and *Culex fatigans* in experimental huts treated with DDT and BHC.—Bull. ent. Res., **42**, pp. 1-20.
- WILKINSON, P. R. (1951). Distribution and fate of *Anopheles gambiae* and *A. funestus* in two different types of huts treated with DDT and BHC in Uganda.—Bull. ent. Res., **42**, pp. 45-54.
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FIG. 1. General view of hut and method of carriage by hand.



FIG. 2. Hut, showing one entrance trap protruding into the hut, opposite window, bed, etc.



FIG. 3. Detail of trap.

A NOTE ON THE PARASITISATION OF THE OÖTHECAE OF
PERIPLANETA AMERICANA (L.) BY THE CHALCID,
SYNTOMOSPHYRUM GLOSSINAE WTSTN.

—A CORRECTION.

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Nash (1955) published a note in which he recorded *Syntomosphyrum glossinae* Wtstn., a Chalcid parasite of the pupae of tsetse flies, parasitising the oöthecae of *Periplaneta americana* (L.) at this Institute. After publication of this paper, Dr. B. D. Burks, of the U.S. National Museum, Washington, D.C., U.S.A., suggested in a letter to Dr. Nash that the parasite in question may have been *Tetrastichus hagenowii* (Ratz.), rather than the very similar *S. glossinae*. *T. hagenowii* is a world-wide parasite of *P. americana*. As Dr. Nash was too busy to investigate this problem he asked me to do so on his behalf and this note gives the results of the investigation carried out.

S. glossinae was first recorded from West Africa by Nash (1947) who obtained it from pupae of *Glossina palpalis* (R.-D.) collected in the Kaduna area; the specimens were identified by Mr. G. E. J. Nixon of the Commonwealth Institute of Entomology. Since then this parasite has frequently been brought in to the laboratory in collections of wild tsetse pupae and has caused much trouble in the fly-breeding rooms at this Institute. When, in November 1953, Chalcid parasites were found swarming in the main fly room and emerging from oöthecae of *P. americana*, Dr. Nash assumed they were once more *S. glossinae* and published his note (Nash, 1955). After the receipt of Dr. Burks' letter the fly room was searched and two Chalcids were collected from the window panes. It could not, of course, be guaranteed that these were from cockroach oöthecae. Both were sent to Dr. Burks and identified as *T. hagenowii*. The two species are superficially identical but *S. glossinae* has all coxae yellow whereas in *T. hagenowii* only the coxae of the second and third pairs of legs are yellow; further, they differ generically in that *T. hagenowii* has a pair of sub-lateral longitudinal carinae on the scutellum which are absent in *S. glossinae*.

During the next few months six batches of *T. hagenowii* which emerged from cockroach oöthecae, and two batches of *S. glossinae* which emerged from pupae of *G. palpalis*, were subdivided and each half placed with either cockroach oöthecae or tsetse pupae of assorted ages. In no case did *T. hagenowii* succeed in parasitising tsetse pupae, or *S. glossinae* in parasitising cockroach oöthecae, although both Chalcids successfully parasitised their normal host.

In the light of this evidence it seems likely that the parasites described by Nash (1955) as attacking the oöthecae of *P. americana* were in fact *T. hagenowii* and not *S. glossinae*. Dr. Nash wishes me to convey his regrets to anyone who has been misled by his paper and to apologise for any inconvenience he may have caused.

Summary.

A correction is made to a paper by Nash (1955) in which *Syntomosphyrum glossinae* Wtstn., a Chalcid parasite of the pupae of tsetse flies, was wrongly

recorded as parasitising the oöthecae of *Periplaneta americana* (L.). The parasite in question was almost certainly the very similar *Tetrastichus hagenowii* (Ratz.) which is a world-wide parasite of *P. americana*. There is no evidence that either parasite can attack both *P. americana* and *Glossina palpalis* (R.-D.).

References.

- NASH, T. A. M. (1947). A record of *Syntomosphyrum glossinae* from Nigeria.—*Bull. ent. Res.*, **38**, p. 525.
- NASH, T. A. M. (1955). A note on the parasitisation of the oöthecae of *Periplaneta americana* (L.) by the Chalcid, *Syntomosphyrum glossinae* Wtstn.—*Ibid.*, **46**, pp. 111–112.
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AN INVESTIGATION OF THE POSSIBILITIES OF BIOLOGICAL
CONTROL OF *MELITTOMMA INSULARE* FAIRM. (COLEOPTERA,
LYMEXYLONIDAE), A SERIOUS PEST OF COCONUT
IN THE SEYCHELLES.

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(PLATE XIV.)

Melittomma insulare Fairm. has been recognised as a pest of coconuts in the Seychelles since the beginning of this century. Its biology, damage caused and suggestions for control have been described by Vesey-FitzGerald (1941a) and more recently a thorough study of the pest has been made by Brown (1954). In the last few years increased attention has been focused on this pest, since, with the biological control of scale insects effected in 1938 (Vesey-FitzGerald (1941b)) *Melittomma* now remains the most serious pest of coconuts. It had been suggested by planters in the Seychelles that this pest was increasing its attack and becoming serious in areas which had previously suffered little. Applications for technical assistance in this problem had been made by the Seychelles Government on several occasions. Eventually, after the Commonwealth Institute of Entomology had stated that chemical control methods did not appear to hold out any great promise, an enquiry was submitted to the Commonwealth Institute of Biological Control concerning the possibilities of biological control. A memorandum was prepared in which it was pointed out that apart from *M. insulare* in the Seychelles and Madagascar little was known of the biology of Lymexylonids and that no parasites or predators had ever been definitely recorded from a member of this family. It was stressed that any biological control investigation would perforce be long and difficult and that the chance of obtaining a useful predator or parasite for introduction into the Seychelles was remote. However, until such an investigation had been made the possibilities of biological control would remain unknown.

In spite of the unpromising nature of this investigation the problem was considered sufficiently serious, and the Seychelles Government requested that a search for parasites and predators be undertaken. As a preliminary, and in order to obtain first-hand information on the biology of *M. insulare*, a short visit was paid to the Seychelles in February and March 1952. This was so arranged as to coincide with a visit that was being made by Mr. Vesey-FitzGerald, who had worked on the problem prior to 1941 and was principally interested in the ecological aspect and the status of the pest as compared with what he had found in his earlier work.

At the same time Mr. Vesey-FitzGerald was able to place his experience at the disposal of Mr. E. S. Brown, of the Commonwealth Institute of Entomology, who was about to begin a study, scheduled to continue for about a year, of the problem in general, with special reference to reassessment of the possibility of insecticidal control of *Melittomma*. Thus there were, for a time, three entomologists in the Seychelles investigating this problem, each along somewhat different lines (see Brown, 1954).

As stated above, the biology and status of *Melittomma* as a pest have already been described by Vesey-FitzGerald and Brown, and the occurrence of the pest in Madagascar by Frappa (1948).

Damage caused by *M. insulare*.

It does not seem that *Melittomma* is particularly prevalent in trees growing on any definite soil-type or in any other situation, though trees growing in coral sand appear to be somewhat less frequently attacked. Wherever coconuts are planted on those islands in which the pest occurs, *Melittomma* is to be found, and its local abundance or otherwise depends largely on the physiological conditions of growth of the coconut trees in the area. This, in turn, is dependent on the age of the tree and the general environmental conditions.

Where infestation is generally heavy, young trees may apparently be attacked as soon as a woody trunk begins to form, and before a well-defined root collar has developed. Several young trees five to seven years old, but growing poorly, were examined and found to bear damaged patches of tissue externally below soil level, indicating where *Melittomma* larvae had entered. Beneath this was a bruised section bearing larval tunnels leading inwards to where the larvae were actively feeding. It is thought that such a small area may act as an attractant to ovipositing females, in which case a tree once damaged becomes more liable to subsequent attack. If this is so, then within the first ten to 15 years of its life a tree may be subject to a series of attacks. The resulting damage to the tree, quite apart from the actual number of larvae in the wood, depends largely on the physiological state of the tree. In a rapidly growing healthy young tree, growing under favourable conditions, *Melittomma* larvae appear to develop rapidly and the "fermentation" and necrotic tissue produced is widespread, advancing well ahead of larval feeding. Such necrosis may spread downwards to the roots, or these may be actually bored, and trees have been seen where nearly all the roots, excepting those at the extreme base of the bole, have been killed. This damage, coupled with the elimination of the vascular bundles in the necrotic area of the wood, may be sufficient to prevent adequate water and nutrients from reaching the crown of the tree and this may then die. The outer leaves die first, leaving the central shoot standing and living for some time. Such an effect may be rapid, and the death of the crown sudden, if a large number of *Melittomma* larvae occur in a sappy tree. If the extent of the damage causes a slower death, preliminary symptoms such as an elongation of nuts and failure to develop fully may precede the final dying of the crown (Type III and some of Type II, Vesey-FitzGerald, 1941a). If, however, the tree is growing under less favourable conditions the wood may not be as soft and sappy, and the *Melittomma* larvae may not develop so rapidly, or the wood decay so quickly around and in front of their tunnels. In this case the slower-growing tree, with less effect from *Melittomma*, may be able to maintain a sufficiently large root and unaffected vascular system to keep its crown alive, albeit with a poor yield of nuts. In such cases progress of *Melittomma* attack with its consequent "fermentation" and breakdown of woody tissue may be so slow, and the outer wood so hard that, whilst the tree remains alive, a cavity develops in the centre of the bole. This cavity usually develops a hole to the exterior at about ground level and within it *Oryctes* larvae and termites usually complete the breakdown of the decaying woody tissues. Thus a condition develops where the tree is hollow at the centre of the base with, perhaps, *Melittomma* larvae in greater or lesser numbers developing at the root collar and at the periphery and apex of the cavity. If the numbers of larvae are sufficient these trees may "die standing" at any time. If, on the other hand, the number of larvae is insufficient to cause this, these trees may live indefinitely, the yield of nuts being often little impaired by the "hollow core", where vascular bundles would have been fewer than elsewhere.

These trees are "hollowed-out cases" (Type I of Vesey-FitzGerald, 1941a) and may live indefinitely so long as the root-system remains sufficient to hold the tree mechanically. However, in an unusually strong wind, particularly if, by cultural methods, a heavy yield of nuts has been encouraged, these are liable to be blown

over far more readily than sound trees. Thus, with this type of damage, what might be considered as a premature ageing of the tree is produced.

In trees where roots are being gradually attacked, more roots are developed adventitiously at the root collar with the result that roots develop higher and higher out of the ground to produce a condition found normally only in much older trees. These roots may often not even reach the ground and probably afford, in the crevices between the roots, further points for oviposition and entry into the tree of young *Melittomma* larvae.

It is now believed that, the Type-IV damage of Vesey-FitzGerald's classification, that of the "pinched top" trees cannot, in general, be ascribed to *Melittomma*. It is considered to be due to completely unsatisfactory growth conditions usually associated with planting on hillsides that are subject to erosion where mineral and/or water availability is inadequate for normal growth. The tree struggles along without producing a satisfactory crown, and few, if any, nuts. This may continue indefinitely, or, if the soil becomes gradually more exhausted and conditions deteriorate, the trunk may become progressively pinched at the top and the crown may eventually die, giving a very characteristic appearance. A similar type of growth-form may be seen in some trees growing in unsuitable swampy conditions. *Melittomma* larvae may be present in these trees, but are usually few in number owing to the poor physiological state of the trees. In some few cases they may be an additive cause in producing pinching of the top and finally death, but it is thought that this type of damage, either on hillside or swamp, cannot usually be directly ascribed to *Melittomma* attack.

It was the practice at one time to estimate *Melittomma* damage in any area by examining a number of trees externally for signs of *Melittomma* attack and classifying them in four groups: (1) healthy, (2) hollowed-out cases, (3) fallen and dead, (4) pinched top. This classification was not satisfactory because a number of trees classified as healthy may, in fact, contain *Melittomma* larvae, and the "frass" may be extruded slightly below ground level and not be visible; "hollowed-out cases" are often past any active attack by *Melittomma* and "pinched tops" are not due to the pest. Thus Vesey-FitzGerald's (1941a) table and graphs do not, in fact, indicate any correlations between the effects of *Melittomma* attack and soil conditions, but rather that "pinched tops" occur on unsuitable, poor, hillside soils.

Thus, to summarise: *Melittomma* attacks may occur in any area, and the damage caused is due, not only to the intensity of attack, but also largely to the age and physiological condition of the trees involved. Conditions suitable for the rapid development of the larvae will result in a rapid build-up of the *Melittomma* population and increased severity of attack. Further details of the progress of an infestation, etc., are given by Brown (1954).

In stands of old trees, which are usually mostly "hollowed-out cases", little active *Melittomma* damage is normally being caused, even though a few larvae may be present in nearly every tree; thus the total *Melittomma* population is small. In stands of young trees growing under favourable conditions, numbers of *Melittomma* may be considerable, and when these trees reach an age of 15 to 25 years the population may have built up to such an extent and the larval damage be so severe that many of the trees will die standing. An example of the former is to be found in northern Mahé and at Côte d'Or, Praslin; one of the latter form of attack is seen at Gardner's Estate, Praslin.

It seems that no definite rule can be made, and that individual trees react differently, depending on the severity of attack and on the age and general physiological condition of the tree. When considering cultural or chemical control of the pest, each tree must therefore, to a certain extent, be considered individually.

It is difficult to assess the economic value of the damage caused. With an estimate (Department of Agriculture) of 4,000,000 trees in the Seychelles and

three nuts per pound of copra, present export figures for copra indicate approximately ten nuts per tree per annum. Even allowing a very high figure for local consumption of nuts and coconut products and increasing this figure to 15 nuts per tree it is still an appallingly low average. If 50 per cent. of the trees were "pinched top" and non-bearing on account of being planted in unsuitable, usually hillside conditions, or because they had not yet reached bearing age, then this would only increase the annual yield of bearing trees to 30 nuts per tree (compared with 80-120 for good-bearing coconut trees). Since the virtual elimination of scale insects a large proportion of blame for this low yield must be attributed to *Melittomma*. Very serious, too, is the actual loss of trees, either "hollowed-out" bearing trees blown over by wind (Côte d'Or estimates about 150 trees or 1 per cent. per annum and this is certainly a low figure) or young trees just beginning to bear. With fluctuating prices for copra it is impossible to state the value of the loss, but it is sufficient that *Melittomma* causes very serious damage to what is by far the most important means of livelihood in the Seychelles.

Biological Control.

There are three possible types of control measure, cultural, chemical and biological, and brief mention may be made of all three. Both cultural and chemical control are dealt with in detail by Brown (1954).

With regard to cultural practices it should be remembered that *Melittomma* larvae seem to be more abundant and probably develop faster in quickly growing, healthy, young trees and that an old "hollowed-out" tree is safer from being blown over by wind when not bearing a heavy crop of nuts. It would, therefore, appear that mediocre trees, not growing too well and not bearing too many nuts are more likely to withstand *Melittomma* damage. Hence, therefore, careful attention to provide optimum growing conditions and the application of manures is likely if anything to increase *Melittomma* damage.

In those islands where *Melittomma* occurs, planting of new areas of trees at present seems to be fraught with danger. It would seem better merely to replace trees individually as they die or fall.

A large number of trees produce virtually nothing, particularly those on hill-sides that are subject to erosion. These completely useless trees are very evident and every effort should be made to persuade planters to get rid of them. They act as a reservoir, albeit of only comparatively few individuals per tree, of *Melittomma*, and represent a complete waste with regard to land utilisation. Even in very bad areas of this type some planters are putting out new trees although these will undoubtedly suffer the fate of their predecessors.

Large-scale experiments to determine the possibilities of economic control of the pest by means of insecticides are described by Brown (1954).

Even if the cost of an effective application of insecticides is brought down to a very low level and the residual effect of one application is extended over a long period, the problem of *Melittomma* control is still difficult. A tree from ten to 20 years old which is beginning to show signs of *Melittomma* attack is likely, with rapid disintegration of its centre wood due to the "fermentation" preceding the larval burrows, to be past saving, even though the *Melittomma* larvae are all killed by insecticidal treatment. The older "hollowed-out" type of tree is almost getting over the stage when *Melittomma* damage is serious. It is in fact the young trees that are worth treating, and this means that every young tree, whether showing *Melittomma* damage or not, must be treated regularly. Also, there is evidence that young trees (certainly at five years old on some soils) are being attacked, and if such trees are to be kept undamaged a preventative treatment must be applied from about the third or fourth year of growth until the thirtieth year or even more, when the wood may become too hard for acute

Melittomma attack. Quite apart from the economics of this, it will be very difficult to persuade the planters that such a long-term policy is necessary, particularly with absolutely no certainty of the price of copra when young trees so treated begin to bear.

It has been indicated above that, with present knowledge, cultural methods of control of *Melittomma* are not likely to succeed and that probably the best that can be done along these lines is the production of a comparatively poorly bearing tree, which, owing to its poor condition, is unlikely to succumb to *Melittomma*.

Chemical control methods may prove economically possible, but consideration of the probable necessity for repeated preventative applications of insecticides, that nearly all trees will have to be treated, coupled with the natural reluctance of the planters to undertake an expensive long-term programme when the value of the crop is so uncertain, make successful control by these methods on an island-wide scale very doubtful.

There then remains biological control. If possible, application of this method is, of course, to be preferred, since once control by an introduced parasite or predator is established, no further expense or effort on the part of the planter is necessary. In the Seychelles, coconut planters have already had an outstanding example of the successful application of this method in Vesey-FitzGerald's work in controlling coconut scales by means of introduced Coccinellids. Unfortunately, as has been repeatedly stressed, *Melittomma* control presents a very different problem. The scales were probably pests introduced without their natural enemies, and Coccinellids are well-known predators on scales. *Melittomma insulare*, however, occurs elsewhere only in Madagascar where, if there are any parasites, there appear to be no efficient ones. Thus natural enemies have to be sought of other allied species of beetles and there are no records of parasites definitely attacking any species of the LYMEXYLONIDAE. Two records of parasites of *Hylecoetus dermestoides* (L.)—*Habritys brevicornis* (Ratz.) and *Perniphora robusta* Ruschka—in the Parasite Catalogue of the Commonwealth Institute of Biological Control are undoubtedly mistakes. Thus nothing is known of the parasites of LYMEXYLONIDAE and only little of the biology of a very few species of the family. The nature of the life-history of the known species makes it seem doubtful if effective larval parasites will be found, and parasites or predators of the eggs, or possibly pupae, are more likely to prove successful. The investigation, therefore, of the possibilities of the biological control of *M. insulare* will be extremely difficult, as there is little indication of where search for parasites, if in fact any exist, should be made.

Hence preliminary investigations were made as to the distribution and biology of other species of Lymexylonids.

Distribution of other Species of Lymexylonidae.

During the course of the journey to and from the Seychelles several museums and libraries were visited in order to gather as much information as possible from the literature and from data on specimens concerning the distribution and relative abundance of other Lymexylonids. These records are given below as they constitute a summary of much of the information on this little-known family.

In a number of instances specimens of the same species have been placed in different genera in different museums, particularly with *Hylecoetus* and *Melittomma*. In these cases, where specific identity has been certain, all specimens have been considered in the genus favoured by the majority of authorities. No claim is made that the grouping below represents a correct natural classification. More recent examination of this question has been made by Lane (1955).

In the following list:—

B.M.	denotes	British Museum (Natural History), London.
A.M.N.H.	„	American Museum of Natural History, New York.
U.S.N.M.	„	United States National Museum, Washington.
M.H.N.	„	Musée d'Histoire Naturelle, Paris.
N.C.	„	National Collection, Ottawa.

Genus **Hylecoetus**

H. americanus Harris

Recorded by Schenkling (1915)* from North America. According to Leng (1920) a synonym of *H. lugubris* Say.

H. australis (Erichs.)

Placed in genus *Lymerxylon* by Erichson (1842, p. 147); in present genus by Lea (1912).

Recorded by Schenkling from Australia—Victoria, eastern Queensland and New South Wales. There are specimens in the National Museum of Victoria. There is also a single specimen in the collection of the Department of Agriculture, Tasmania, from Preston, in the north-west part of that island.

H. cossis Lewis

Recorded by Schenkling from Japan.

H. cylindricus Dej.

A single specimen taken at light in South America. Lacordaire (1830).

H. dermestoides (L.)

This is a common species in Europe, and has also been recorded from Siberia and Kamchatka (Schenkling). There are many papers dealing with the damage caused by this species and its biology (*e.g.*, Thomsen, 1950). In Scotland a Nitidulid beetle, *Rhizophagus dispar* (Payk.), has been recorded as feeding on the eggs of this species (Ferguson, 1920) which were found to be locally abundant, adults being on the wing in May and June. As mentioned above (p. 689), two parasites recorded from this species are not in fact from this host (Ruschka, 1923).

H. flabellicornis (Schneider)

In Schenkling this species is recorded from Germany, Finland, Russia and Bukovina. There is one specimen from Königsberg (M.H.N.) and another in the United States National Museum. It is possible that this species and *H. dermestoides* have sometimes been confused.

H. fuscipennis Lea

Recorded from New South Wales, Australia (Lea, 1912). There are specimens in the National Museum of Victoria, Australia.

H. lateritius Fairm.

One specimen recorded by Dr. ten Kate from Surinam (Fairmaire, 1887).

H. linearis Lea

Recorded from New South Wales (Lea, 1912). Specimens in the National Museum of Victoria.

* Except where otherwise indicated, all references to Schenkling are to Schenkling (1915).

H. lugubris Say

This is apparently fairly widespread over eastern North America and specimens have been seen from the vicinity of New York City and Cornwall, Conn. (A.M.N.H.); Lyme, Conn.; Trenton, N.Y.; Rivervale, N.J.; Delaware Co., Pa.; Plummer, Md.; Dead Run, Va.; West Virginia; Louisville, Ky.; and Marquette, Mich. (U.S.N.M.); Monagelia Co., W. Va.; Casselmann, Province of Quebec; Laniel, P.Q.; Knowlton, P.Q.; Wright, P.Q.; Fredericton, N.B.; Merivale, Ont.; Britannia, Ont.; Arnprior, Ont.; and Hawthorne, Ont. (N.C.).

It has been reared from logs of *Liriodendron* (Virginia and West Virginia) and poplar (Lyme, Conn. and Fredericton, N.B.).

H. pervagus Olliff

Recorded from Queensland, where it is apparently not uncommon, and also from Lord Howe Island (off the east coast of Australia), whence there are specimens in the National Museum of Queensland and one in the British Museum (Natural History).

H. vigilans Lea

Recorded from Queensland (Lea, 1912). Specimens from Queensland in the British Museum (Natural History) and in the National Museum of Victoria.

Genus **Melittomma****M. africanum** (Thoms.).

Specimens have been seen from the Gold Coast, Fernando Po, Nyasaland and South Africa (B.M.); Liberia (U.S.N.M.); French Guinea, French West Africa and French Congo (M.H.N.); and one specimen from the Kaimosi Forest, Kenya, in the Coryndon Museum, Nairobi. It is also known from Southern Nigeria and Sierra Leone where it is widespread but not common. In West Africa, larvae of *Melittomma* sp. (probably *africanum*) have been found in the dead trunks of *Ficus exasperata* Roxb. (Moraceae), *Funtumia africana* Stapf. (Apocynaceae), *Triplochiton scleroxylon* K. Schum. (Malvaceae) and *Terminalia superba* Eng. & Diels. (Combretaceae).

These larvae were in small holes in the undifferentiated heartwood. From them adults emerged over a long period. Associated with them were Elaterid larvae which may be predacious on the *Melittomma*. Specialised conditions were apparently required by ovipositing females, as few logs were attacked, but these heavily so.

M. albitarsis Blair

Recorded from India, where, in Bengal, larvae were found in *Bombax malabaricum* D.C. (Bombacaceae) (Gardner, 1937).

M. angustum (Tasch.)

Recorded in Heyne & Taschenberg (1908). Listed as a questionable synonym of *M. brasiliense* (Lap.) by Schenkling.

M. auberti Fairm.

The type specimen, lacking locality data but labelled 1892, was seen (M.H.N.). This species is recorded by Schenkling from Senegal.

M. benitonum (Fairm.)

The type specimen from the French Congo was seen (M.H.N.). See de Laporte de Castelnau (1840) and Fairmaire (1901).

M. brasiliense (Lap.)

Specimens seen from Brazil, Nicaragua and Mexico (B.M.); Paraguay, Brazil, French Guiana, Barro Colorado (Panama Canal Zone), Panama, Guatemala and Mexico (U.S.N.M.); and Brazil (M.H.N.). Specimens from Peru, Bolivia and Brazil (U.S.N.M.) may also be of this species. There is a large number of specimens (about 40) from Barro Colorado, but this may be due only to intensive collection there. There are larvae from *Castellia mexicana** from Costa Rica (U.S.N.M.). A single specimen was taken in Trinidad, B.W.I., in 1953.

It is mentioned by de Laporte de Castelnau (1832) under the name of *Hylecaetus brasiliensis* Dej. as being in galleries in "Bolets", presumably a fungus, *Boletus* sp. It is also recorded by Germer (1912).

M. cribricollis Fairm.

Type specimen seen, from Moupin, China (M.H.N.).

M. insulare Fairm.

This is the pest of coconut trees in some of the islands of the Seychelles Archipelago and in the north-western part of Madagascar. There are specimens from the Seychelles (B.M. and M.H.N.). It is also rumoured to occur in the Comoro Islands, Isle Ste. Marie (Madagascar) and Frigate Island (Indian Ocean) but none of these reports has been confirmed by Vesey-FitzGerald (1941a). Details of the biology of this species and damage caused are given above and also in various annual reports of the Seychelles Department of Agriculture (Vesey-FitzGerald, 1938 and 1939), Vesey-FitzGerald (1941a), Frappa (1948), Brown (1954).

M. javanicum (Chevr.)

This species is mentioned by Fairmaire (1887). Specimens seen were from Dutch Timor, Celebes, Philippines, Andaman Islands and Ceylon (B.M.); and Philippines (U.S.N.M.). It has also been recorded (Schenkling) from Java, Sumatra, western New Guinea, Tandjong Arawa and Serdang. One larva, undoubtedly misdetermined but assigned to this species, was seen from Estrella, Costa Rica (U.S.N.M.).

M. marginellum Schenkl.

Described by Schenkling (1914) and recorded from Ecuador. Specimens seen from Brazil (B.M. and M.H.N.).

M. perrieri (Fairm.)

The type specimen from Perrier, Madagascar, was seen (M.H.N.). See Fairmaire (1901).

M. ruficollis Pic

One specimen seen from Corupa, Brazil (A.M.N.H.), listed as a variety of *M. lateritium* (Fairm.) by Blackwelder (1945).

M. sericeum (Harris)

There seems possibly to be a certain amount of confusion regarding the identity of this species and *H. lugubris* Say in records and labelled specimens. This species seems to be well distributed over the eastern United States and specimens were seen from Delaware Water Gap, Black Mts., N.C. (A.M.N.H.); and Plummer Island, Md. (U.S.N.M.), where records show that it attacks old oak and chestnut trees.

* It is impossible to determine what species of tree is referred to here.

Hopkins (1894) records larvae in chestnut stumps at Morganstown, W. Va. Riley (1874) mentions it in Missouri, while Hagen (1886) describes larvae, which are very similar to those of *M. insulare*, from elm at Trenton Falls, N.Y.

M. validum Schenk.

See Schenkling (1914). Specimens seen from Brazil (B.M. and M.H.N.).

Also in the museums there were a number of undetermined species of this genus—from Australia, Philippines, Celebes, Singapore, Andaman Islands, Assam, Ceylon, Côte d'Ivoire, French Guinea and Congo, Belgian Congo, Sierra Leone, Brazil, Peru, French Guiana, Venezuela, Ecuador, Panama, Costa Rica and Guatemala.

Genus **Lymexylon**

L. adelaidae Blk.

Blackburn (1898) described this species from Adelaide, Australia.

L. navale (L.)

This is a widespread European species, and there are many references to it in the literature, *e.g.*, Judeich & Nitsche (1885), Sidebotham (1873), van Emden (1943), Houlbert & Bétis (1904).

Specimens in the museums were from Windsor, Durham, Pembroke Dock, "Anglia", "Gallia merid.", "Gallia austral" (B.M.); Fontainebleau, Compiègne, Isère, Dunkerque, Tyrol (M.H.N.); Frankfurt-a.-Main and Fontainebleau (U.S. N.M.); and it is recorded as attacking oak and chestnut in France. More recently some large old oak trees near Worksop, from which wood was being cut to repair York Minster, were found to contain larvae of this species. These logs had been cut for some six to seven years.

Besides these there is a specimen in the Musée d'Histoire Naturelle labelled as a new species from Australia, and two others similarly labelled, one from Tasmania, the other from New South Wales, in the British Museum.

As mentioned above, *Melittomma sericeum*, *Hylecoetus dermestoides* and *H. australis* are sometimes referred to under this generic name.

Genus **Atractocerus**

A. bicolor Strohm.

This species is recorded by Schenkling from New Guinea.

A. bifasciatus Gestro

The type and other specimens seen from New Guinea (M.H.N.).

A. blairi Gardner

Specimens have been reared in Assam from a log of *Terminalia myriocarpa* Heureka & Muell. Arg. (Combretaceae) (B.M.).

A. brasiliensis Lep. & Serv.

Reference is made to a larva of this species found in a log of mora, *Mora excelsa* Benth. (Leguminosae), in Trinidad by Swabey (1935). Museum specimens were seen from Mexico, Nicaragua, Costa Rica, British Honduras, Dominica, B.W.I. and Brazil (B.M.); Mexico, Colombia and Peru (A.M.N.H.); Brazil, French Guiana, Panama, Costa Rica, Guatemala and Mexico (M.H.N.); and Paraguay, Brazil, Venezuela, Ecuador, Panama, Trinidad, B.W.I., Grenada, B.W.I., St. Vincent, B.W.I., Guadeloupe, F.W.I. and Puerto Rico (U.S.N.M.). Nearly all of these specimens were probably taken at light. Those from Costa Rica were taken at all times of the year and therefore there appears, in this area,

to be no definite season for emergence. In the United States National Museum there are also larvae of what is almost certainly this species from Barbados (collected by Ballou, 1905) and from logs of *Prioria copaifera* Griseb. (Leguminosae) from Costa Rica.

Mr. R. W. E. Tucker (*in litt.*) tells me that this species has been found in the larval stage in dying trunks of *Albizzia lebbek* (Benth.) (Leguminosae) in Barbados, and further records of this species in Trinidad are given in detail below.

A. brevicornis (L.)

This species is widespread over the whole of Africa, excepting possibly the northern parts, and it seems likely that there is only this single species of the genus present on this continent. Specimens have been seen from the Gold Coast, Ashanti, Nigeria, Calabar, Sierra Leone, San Tomé, Fernando Po, Cameroons, Congo, Central Africa, Uganda, Lake Victoria, Kenya, Nyasaland, German East Africa, Tanganyika, Rhodesia, Natal, Pondoland, Zululand, South Africa, Mozambique and Madagascar (B.M.); from Cameroons, Congo and South Africa (A.M. N.H.); Liberia, Gold Coast and West Africa (U.S.N.M.); and West Africa, Congo, Southern Rhodesia, Zambesi, Mozambique and Madagascar (M.H.N.). There are also several specimens from Uganda in the collection of the Department of Agriculture at Kawanda, Uganda. In addition, larvae have been recorded from the Gold Coast in a "mahogany" log, presumably *Entandrophragma* sp. or *Khaya* sp. (Meliaceae), and from the Belgian Congo in a "limba" log. Gardner (*in litt.*) records larvae from the heartwood of a log of *Ekebergia ruppeliana* A. Rich. (Meliaceae) in Tanganyika and from a log of *Mildbraediodendron excelsum* Harms. (Leguminosae). It has also been recorded from teak, *Tectona grandis* L. (Verbenaceae). In West Africa the species is said to be widespread but not common in Southern Nigeria and Sierra Leone, and larvae have been obtained in recently killed logs of *Ricinodendron africanum* Muell. Arg. (Euphorbiaceae) and *Triplochiton scleroxylon*. In the case of the former species trees killed by fire in January 1947 produced adult beetles on 21st May 1947. Large Elaterid larvae occurred in some of the tunnels and were thought to be predacious on the *Atractocerus* larvae. Larvae have been found in dying cashew nut, *Anacardium occidentale* L. (Anacardiaceae), at Mombasa, Kenya (Mr. E. S. Brown, *in litt.*, 1953).

A. bruijni Gestro

Specimens from the Philippines (B.M.) and Perak (M.H.N.). Recorded by Schenkling from Philippines, Celebes, Perak and Hong Kong.

A. emarginatus Lap.

Specimens seen from Perak, Penang, Singapore, Sumatra, Java, Celebes, Sarawak, Siam, Burma, India and Ceylon, and larvae from a log of *Buchanania latifolia* Roxb. (Anacardiaceae) from Gorakpur, U. P., India (B.M.); from the Philippines, Java and India (U.S.N.M.); the type specimen from Sumatra and others from Dutch East Indies, Tonkin, Palembang and Malabar (M.H.N.). (See also Fulmek (1930).)

In addition, information has been obtained that the larvae have been found at Negri Sembilan, Malaya, in decaying logs and in stumps of rubber trees, *Hevea brasiliensis* Muell. Arg. (Euphorbiaceae), (Mr. H. T. Pagden, *in litt.*). A female taken at light laid eggs which hatched to campodeiform larvae. Adults are often covered with mites (*cf.* *A. brasiliensis*, below). In Sarawak an *Atractocerus*, probably this species, is said to be common, individual logs being heavily attacked.

A. gracilicornis Schenkl.

One specimen seen from California (1851) (M.H.N.); probably the same record as that in Schenkling.

A. kreuslerae Pasc.

Recorded by Schenkling from South Australia. Specimens seen from New South Wales and Western Australia (B.M.).

The life-history of this species has been described by Clark (1925). The adults are common and fly in swarms. Eggs are laid on any damaged surface of cut logs of many species of *Eucalyptus*. The larvae bore into the wood in a manner similar to that of *M. insulare*, and the life-cycle appears to be over a year. Further observations were made in Victoria on this species after a large number of trees had been killed by bush fires.

A. lymexyloides ?

Larvae in logs of mahogany, *Swietenia mahagoni* Jacq. (Meliaceae), from British Honduras (U.S.N.M.). The name on the label is of no described species of *Atractocerus* and it is likely that the specimen is in fact *A. brasiliensis* Lep. & Serv.

A. morio Pasc.

There are specimens from the Moluccas (B.M. and M.H.N.) and from the Philippines (B.M.); in addition it is recorded by Schenkling from New Guinea and Celebes.

A. niger Strohm.

In the British Museum there are specimens from the Nilgiri Hills, India, and one from Madras reared from a log of *Dipterocarpus indicus* Bedd. (Dipterocarpeae). It has also been recorded from the East Indies (Schenkling).

A. procerus Schenkl.

One specimen from Panama (U.S.N.M.). Recorded (Schenkling) from Cayenne, Brazil.

A. quercus Gardner

Specimens in the British Museum from Chakatra, U.P., India were reared from a log of *Quercus dilatata* Rafin. (Fagaceae).

A. reversus Wlk.

The occurrence and control of this species in central India is described by Gardner (1945) and Chatterjee, Bhasin & Bhatia (1950). Larvae were found attacking *Boswellia serrata* Roxb. (Bombacaceae) logs during a period of heavy felling of this species during World War II. Larvae have also been found in *Lannea grandis* Engl. (Anacardiaceae).

Specimens were seen from Ceylon and Malaya (B.M.); Ceylon (M.H.N.) and one from *Boswellia* from Rewah State (U.S.N.M.).

A. schenklingi Heller

Specimens seen from Celebes (B.M.); and the Philippines (U.S.N.M.).

A. valdivianus (Phil.)

Specimens from Chile (B.M. and U.S.N.M.).

There were also, in the museums visited, undetermined specimens of this genus from New Guinea, Borneo, Sarawak, Sumatra, China, Perak, Penang, Philippines, Ceylon, Peru, Bolivia and Guatemala.

Of the 43 species of Lymexylonids listed above, very few are known to be at all common and these have already been indicated. The rest are represented in the museums by a single or very few specimens; of only 16 species were there

four or more specimens. Whether all these species are rare or whether, owing to their habits or habitats, they have only been rarely collected, is difficult to determine. It may be significant that in such localities as Plummer, Md., and Barro Colorado (Panama Canal Zone), where collections have been made by coleopterists interested in Lymexylonids, the species present (*H. lugubris* and *M. brasiliense*, respectively) appear to be relatively common. Since collections have been made in Trinidad, *A. brasiliensis* has been found to be far more common than was formerly supposed, and the specimen of *M. brasiliense* taken in Trinidad is the first record for the West Indies.

As stated above, no insect parasite or predator has ever been recorded from any species of this family, with the exception of the Nitidulid, *Rhizophagus dispar*, recorded as feeding on the eggs of *Hylecoetus dermestoides* in Scotland. In Europe, mite and fungal parasites of *H. dermestoides* have been recorded and this species has been studied intensively without any insect parasites being obtained.

Since *M. insulare* and other species of the same genus occur in Madagascar, a visit there was planned to investigate the possibility of the occurrence of parasites. Unfortunately, at that time a strict quarantine, on account of an outbreak of poliomyelitis, was in force against visitors arriving from Mauritius, and this investigation was impossible. Mr. E. S. Brown, however, paid a short visit there to investigate *Melittomma* infestations in coconuts and found no parasites or predators. Search was, however, made in Kenya, Tanganyika and Uganda forests with light-traps. One specimen of *A. brevicornis* was taken during two weeks' search. No Lymexylonid damage was seen in timber at sawmills.

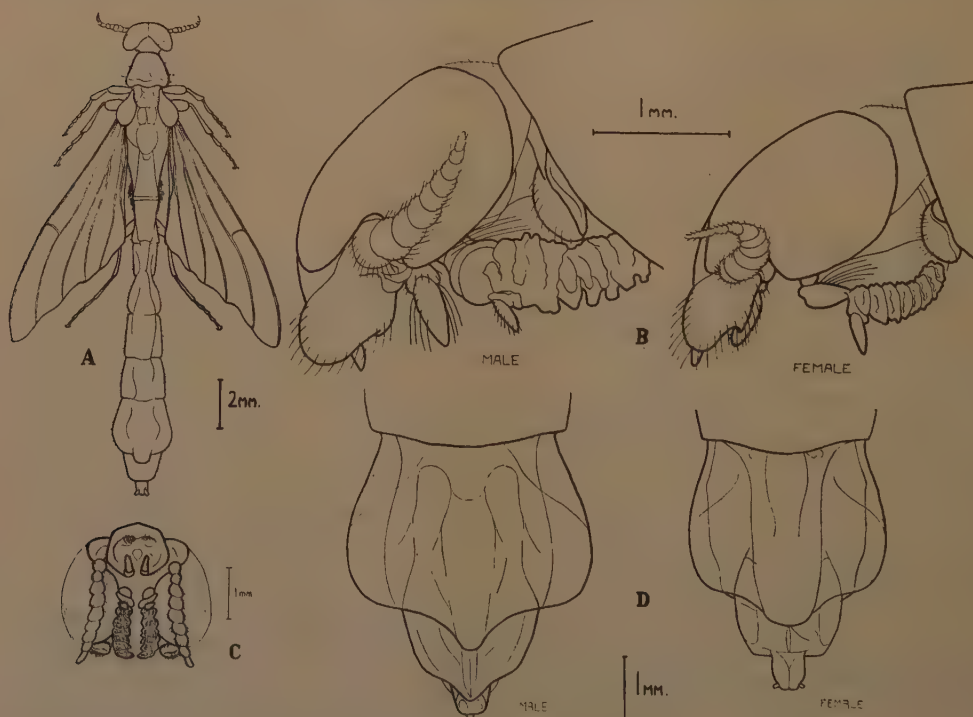


Fig. 1.—*Atractocerus brasiliensis*. (A) adult male; (B) lateral view of heads of male and female; (C) ventral view of head of female; (D) dorsal view of terminal abdominal segments of male and female.

It was therefore decided to investigate, if possible, the biology of *A. brasiliensis* in Trinidad, even though it appeared probable that it was a very rare species.

Investigations on *Atractocerus brasiliensis* in Trinidad.

In the past six years several specimens of *A. brasiliensis* have been taken at light at St. Augustine, Trinidad, but nothing whatever was known of the biology of the species excepting that, as stated above, there is a record by Swabey (1935) that a larva had been removed from a log of mora wood. It seemed entirely unlikely that any serious damage was being caused by the species to standing trees since otherwise more records of it would be available. Also from data available for other species it seemed probable that felled logs might be attacked. Hence a large number of logs of different species of trees was examined in various parts of the island, and although numbers of wood-boring and associated insects were found, no Lymexylonids were encountered for a considerable time.

Eventually, however, a mango log (*Mangifera indica* L. (Anacardiaceae)) containing a number of Lymexylonid larvae was found, the species proving to be *A. brasiliensis*. Subsequently, a large number of mango logs containing *Atractocerus* larvae has been collected. All larvae thus found have been half-grown and large; no logs with very small larvae have been found. The logs were sawn up into pieces 2-3 ft. long and placed individually in domestic cloth bags with the open end tied up with cord. These bags were examined daily for adults. At first few were obtained, but from January to May 1953 some six to ten adults per day emerged from the logs.

These adults (fig. 1) were placed in cages of various shapes and sizes to obtain mating. However, only in one case was this observed and it is almost certain that it did not occur on other occasions since no eggs were laid. On the one occasion observed the male hung in an upright position to the wall of the cage, the female hanging head downwards in an inverted position below him. Unfortunately, she died very shortly after this and no eggs were obtained. In the laboratory, adults lived approximately four days and they were not interested in wood, mango leaves, raisins, sugar-water or wet pads of cotton-wool.

Two females taken at light laid eggs readily, in one case in a metal box, in the other in a glass vial. These eggs are elongately cylindrical, about 4 times as long as broad with rounded ends, about 2.5 mm. in length (fig. 2). They are



Fig. 2.—*Atractocerus brasiliensis*. Eggs.

glistening pearly white without marked sculpturing and were laid in irregular batches in a very viscous fluid, which also exudes at times from the abdomens of females when no eggs are being laid. This fluid remains extremely viscous for at least two weeks, even after the eggs have hatched.

The eggs hatch in about nine days in Trinidad, the developing larvae within appearing greyish towards the time of eclosion.

The larvae on emergence are campodeiform (fig. 3). They have a large head and thorax with prominent mandibles, a narrower cylindrical abdomen tapering gradually posteriorly. The terminal segment bears dorsally a somewhat heavily



Fig. 3.—*Atractocerus brasiliensis*. First-stage larva: (A) lateral view; (B) dorsal view of terminal abdominal segment.

chitinised concave "shield" bearing a number of strong spines and hairs and also numerous sensillae. The larva is about 3.0 mm. in length and about .75 mm. wide at the broadest part. The larvae remain close to the empty egg shells which they eat in the first 24 hours. After this they become active and move quite rapidly. Placed on fairly freshly cut mango logs they moved out of strong sunlight but did not attempt to penetrate into the crevices and cuts made in the log. None was found in the logs subsequently. Hence the earlier larval stages after this are not known, but half- to full-grown larvae (fig. 4) are of similar shape to those of *Melittomma*, the main visible difference being that the terminal segment forms a fleshy, not heavily chitinised, plug, filling the larval tunnel.

The larva burrows in logs of all sizes, the tunnels do not seem to be orientated in any particular direction, and the larger tunnels of mature larvae in small logs

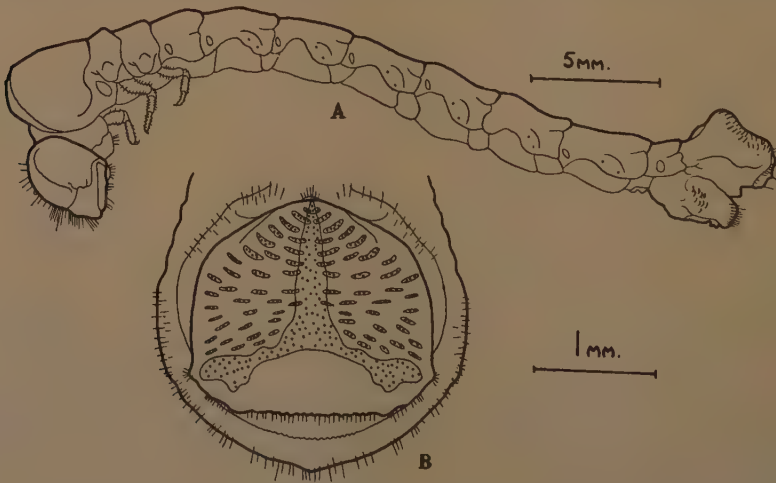


Fig. 4.—*Atractocerus brasiliensis*. Full-grown larva: (A) lateral view; (B) dorsal view of terminal abdominal segment.

often run in circles parallel to the outer surface of the wood (Pl. XIV, fig. 1). Larvae live with their posterior ends pointing towards the exterior opening of the tunnel, and periodically they push chewed wood particles to the exterior by wriggling backwards along the tunnel. Since the wood is already dead, there is no large necrotic area formed in advance of the tunnel as in *Melittomma* and the nourishment of the larva must be squeezed from comparatively dry particles of wood. When about to pupate the larva descends to the opening of the tunnel and enlarges the burrow somewhat, at the same time turning round so that its head faces to the exterior of the hole (even though the larva may still be some distance inside the log). A plug of wood particles blocks off the inner part of the tunnel from this "pupal chamber" and a light plug of the same material is formed in front of the pupating larva. In this widened portion of the tunnel the larva pupates. The pupa is of a normal exarate type (fig. 5), yellowish white at first

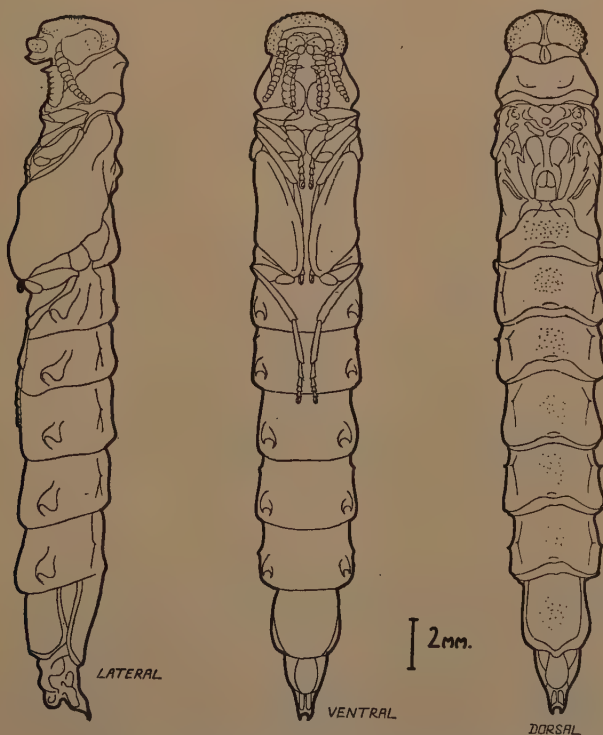


Fig. 5.—*Atractocerus brasiliensis*. Views of pupa.

and gradually darkening to the walnut brown of the adult. After emergence from the pupa the adult may stay in the pupal chamber for some time before chewing through the protecting plug and making its way to the outside of the log (Pl. XIV, fig. 2).

Available records here indicate that in Trinidad this species is generally seasonal, adults emerging during the dry season from the end of December until May or June. Eggs are laid in freshly felled mango logs; those that have been cut for some time are not attacked.

Larvae then mature during the remainder of the year, pupae being formed in December. Actual length of the life-cycle will undoubtedly depend on the dryness, etc., of the wood.

About 25 per cent. of the mango logs of suitable age that were examined were found to be attacked, numbers of larvae per tree being from twelve to over a hundred. No eggs were found in the field. Although a large variety of insects was found on the mango logs examined, none was found in any close association with *Atractocerus*, and it would appear that this species is free from natural enemies in the larval stages. If these do occur they must be extremely rare. It is possible that young larvae hatching from the eggs may be attacked by omnivorous predators, but this has not been observed. Apart from this short period the species is well protected from attack, in the egg stage by the viscous covering, and in the later stages by the habitat.

Although logs of a large number of other species of trees (including *Mora excelsa*) were examined, none was found to be attacked. However, it seems most unlikely that mango, an introduced species, is in fact the chief host for *Atractocerus* and there are undoubtedly other hosts in the forests. Living mango trees were examined but certainly none was attacked.

This species is, in fact, very much more common than was formerly supposed. Numbers must be limited by the ability of the mated female to discover a log in a suitable stage for oviposition during her short life. Trees that are felled are usually cut up fairly soon after for use as firewood and many larvae must be destroyed in this way. However, many logs are left to dry out before being disposed of and this may be sufficiently long for the life-cycle to be completed. In high forest, trees that fall naturally will not be removed in this way.

Although intensive search was made in the area where the single specimen of *Melittomma brasiliense* was taken in Trinidad, no wood infested with Lymexylonid larvae was found. In this same general area a light-trap has been in operation over extended periods but no further specimens of this species have been found.

Thus, although it has been shown that *Atractocerus brasiliensis* is fairly common in Trinidad and that *Melittomma brasiliense* also occurs, no parasites and predators have been found of possible use in the biological control of *M. insulare* in the Seychelles. It seems that at present the one possibility is that *Rhizophagus dispar*, recorded as attacking the eggs of *Hylecoetus dermestoides* in England, might also attack eggs of *M. insulare*. With this in view, investigations of this species will be carried out in England.

Summary.

The biology and general ecology of *Melittomma insulare* Fairm. in the Seychelles is briefly described and the difficulties in the biological control of this pest are stressed.

As much information as possible was obtained concerning the species of the little-known family LYMEXYLONIDAE, particularly with regard to their biology, which in most cases has not been investigated. Several species might warrant further investigation with a view to providing natural enemies for use against *M. insulare*, but in general what is known of their biology does not afford much hope that an effective parasite or predator will be found.

The biology of *Atractocerus brasiliensis* Lep. & Serv. was investigated in detail in Trinidad but no natural enemy was found.

The only possibility is that *Rhizophagus dispar* (Payk.), recorded as attacking *Hylecoetus dermestoides* (L.) in England, might also attack the eggs of *M. insulare*.

References.

- BLACKBURN, T. (1898). Further notes on Australian Coleoptera with descriptions of new genera and species. XXV.—Trans. roy. Soc. S. Aust., 23, pp. 22-101.

- BLACKWELDER, R. E. (1945). Checklist of the Coleopterous insects of Mexico, Central America, the West Indies, and South America. Part 3.—Bull. U.S. nat. Mus., no. 185, pp. 343–550.
- BROWN, E. S. (1954). The biology of the coconut pest *Melittomma insulare* (Col., Lymexylonidae), and its control in the Seychelles.—Bull. ent. Res., **45**, pp. 1–66.
- CHATTERJEE, N. C., BHASIN, G. D. & BHATIA, B. M. (1950). Insect borers of *Boswellia serrata* and their control.—Indian For. Rec. (N.S.) Ent., **8**, pp. 35–51.
- CLARK, J. (1925). Forest pests. The pin-hole borer (*Atractocerus kreuslerae* Pasc.).—J. Dep. Agric. W. Aust., **2**, pp. 138–142.
- VAN EMDEN, F. I. (1943). Larvae of British beetles. IV. Various small families.—Ent. mon. Mag., **79**, pp. 209–223, 259–270.
- ERICHSON, W. F. (1842). Beitrag zur Insecten-Fauna von Vandiemensland.—Arch. Naturg., **8**, pp. 83–287.
- FAIRMAIRE, L. (1887). Coléoptères nouveaux ou peu connus du Musée de Leyde.—Notes Leyden Mus., **9**, pp. 145–162.
- FAIRMAIRE, L. (1891). Notes sur quelques Coléoptères de l'Afrique intertropicale et descriptions d'espèces nouvelles.—Ann. Soc. ent. Fr., **60**, pp. 231–274.
- FAIRMAIRE, L. (1901). Matériaux pour la faune coléoptérique de la Région Malgache (11^e note).—Rev. ent., Caen, **20**, pp. 101–248.
- FERGUSON, D. C. (1920). Trans. R. Scot. agric. Soc., **34**, p. 192.
- FRAPPA, C. (1948). Un parasite du cocotier dans la région nord-ouest de Madagascar.—Agron. trop., **3**, pp. 274–281.
- FULMEK, L. (1930). Zur Kenntnis der Entwicklung von *Atractocerus emarginatus* Cast. (Coleopt.—Lymexylonidae).—Treubia, **12**, pp. 389–394.
- GAHAN, C. J. (1908). On the larvae of *Trictenotoma childreni* Gray, *Melittomma insulare* Fairmaire, and *Dascillus cervinus* Linn.—Trans. ent. Soc. Lond., **1908**, pp. 275–282.
- GARDNER, J. C. M. (1934). On some Coleopterous larvae from Uganda.—Bull. ent. Res., **25**, pp. 149–154.
- GARDNER, J. C. M. (1935). A new Indian species of *Atractocerus* (Col. Lymexylonidae).—Stylops, **4**, pp. 69–70.
- GARDNER, J. C. M. (1936). A new Indian species of *Atractocerus* (Col. Lymexylonidae).—Proc. R. ent. Soc. Lond., (B) **5**, pp. 181–182.
- GARDNER, J. C. M. (1937). Immature stages of Indian Coleoptera (22).—Indian For. Rec., **3**, pp. 127–140.
- GARDNER, J. C. M. (1945). On some Coleopterous larvae from India.—Indian J. Ent., **6**, pp. 111–116.
- GERMER, F. (1912). Untersuchungen über den Bau und die Lebensweise der Lymexyloniden, speziell des *Hylecoetus dermestoides* L.—Z. wiss. Zool., **101**, pp. 683–735.
- HAGEN, H. A. (1886). On the previous stages of Ptinidae and allied groups.—Canad. Ent., **18**, pp. 153–157.
- HEYNE, A. & TASCHENBERG, O. (1908). Die exotischen Käfer in Wort und Bild, p. 192. Esslingen, Schreiber.
- HOPKINS, A. D. (1894). Notes on some discoveries and observations of the year in West Virginia.—Insect Life, **7**, pp. 145–153.

- HOULBERT, C. & BÉTIS, L. (1904). Faune entomologique armoricaine. Coléoptères. 52^e famille. Clérides, pp. 17-18.—Bull. Soc. sci. Ouest, **13**, suppl.
- JUDEICH, J. F. & NITSCHKE, H. (1885). Lehrbuch der Mitteleuropäischen Forstinsektenkunde, **1**, pp. 333-336.
- LACORDAIRE, J. T. (1830). Mémoire sur les habitudes des insectes coléoptères de l'Amérique méridionale.—Ann. Sci. nat., **20**, pp. 185-291.
- LANE, F. (1955). Novos gêneros e espécies de Coleoptera Lymexylonidae e notas sobre *Melittomma* Murray, 1867.—Pap. Dep. Zool. Sec. Agric. S. Paulo, **12**, pp. 141-163.
- DE LAPORTE DE CASTELNAU, F. L. (1832). Mémoire sur cinquante espèces nouvelles on peu connues d'insectes.—Ann. Soc. ent. Fr., **1**, pp. 386-415.
- DE LAPORTE DE CASTELNAU, F. L. (1840). Histoire naturelle des insectes, Coléoptères, **1**, p. 291.
- LEA, A. M. (1912). Descriptions of new species of Australian Coleoptera. Part IX.—Proc. Linn. Soc. N. S. W., **36**, pp. 426-478.
- LENG, C. W. (1920). Catalogue of the Coleoptera of America, north of Mexico.—470 pp. Mount Vernon, N.Y., Sherman.
- PFEIL, —. (1859). Bemerkungen zur Gattung *Hylecoetus* Latr.—Stett. ent. Z., **20**, pp. 74-83.
- RILEY, C. V. (1874). Sixth annual report on the noxious, beneficial and other insects of the State of Missouri, pp. 117-118.
- RUSCHKA, F. (1923). Ein neuer Holzkäferparasit aus der Tribus Cleonymini Schmiedekn. (Hym. Chalcididae).—Ent. Mitt., **12**, pp. 198-201.
- SCHENKLING, S. (1914). Beiträge zur Kenntnis der Lymexyloniden (Col.) 1.—Ent. Mitt., **3**, pp. 317-321.
- SCHENKLING, S. (1915). Derodontidae, Lymexylonidae, Micromalthidae.—Coleopt. Cat., pars 64, 14 pp.
- SIDEBOTHAM, J. E. (1873). Note on capture of *Lymexylon navale*.—Ent. mon. Mag., **10**, p. 83.
- SWABEY, C. (1935). Notes on insect attack on mora (*Mora excelsa* Benth.) in Trinidad.—Leafl. For. Dep. Trin., no. 6, 39 pp.
- THOMSEN, M. (1950). Contributions to the biology of *Xyloterus domesticus* L. and *Hylecoetus dermestoides* L., two wood-boring Coleoptera.—Proc. 8th int. Congr. Ent., Stockholm 1948, pp. 804-811.
- VESEY-FITZGERALD, D. (1938). Entomology.—Rep. Dep. Agric. Seychelles, 1936, pp. 17-18.
- VESEY-FITZGERALD, D. (1939). Entomology.—Rep. Dep. Agric. Seychelles, 1938, pp. 14-16.
- VESEY-FITZGERALD, D. (1940). The control of Coccidae on coconuts in Seychelles.—Bull. ent. Res., **31**, pp. 253-283.
- VESEY-FITZGERALD, D. (1941a). *Melittomma insulare*, Fairm. (Col. Lymexylonidae), a serious pest of coconut in the Seychelles.—Bull. ent. Res., **31**, pp. 383-402.
- VESEY-FITZGERALD, D. (1941b). Progress of the control of coconut-feeding Coccidae in Seychelles.—Bull. ent. Res., **32**, pp. 161-164.



FIG. 1. Cross section of mango log showing *Atractocerus brasiliensis* larval tunnels.



FIG. 2. Mango log showing *Atractocerus brasiliensis* emergence holes.

THE *CULEX* MOSQUITOS OF THE SUDAN.

By D. J. LEWIS

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Species of five subgenera of *Culex* that occur in the Sudan have been recorded by Lewis (1954), and the main purpose of the present paper is to bring up to date the knowledge of the occurrence and distribution of members of the subgenus *Culex*. Additional notes on some members of the other subgenera are also included.

Determinations were made by means of the works of Edwards (1941), Hopkins (1952) and a few papers which are mentioned below.

All locality records are shown in figs. 2 to 11 but the place-names given in the distribution lists are only additional to those given by Abbott (1948), Edwards (1941) and Lewis (1945). The place-names in fig. 1 are additional to those shown by Lewis (1954) and in previous papers mentioned by him. In the locality lists "J." means a jebel or hill, and "K." a khor or watercourse. Initials in brackets refer to collectors whose names are shown in the acknowledgement section.

Some Sudan species occur in the Palaearctic as well as the Ethiopian Region, and, to enable their distribution to be understood, maps of several of them include their known distribution in Egypt (from Kirkpatrick, 1925; Salem, 1933, 1938), Eritrea (Jannone, Ferro-Luzzi & Mara, 1946; Lewis, 1943; Mara, 1946) and western Ethiopia (records kindly supplied by Mr. P. F. Mattingly).

Many Sudan records are based on findings of larvae, and further information is desirable about species which cannot be identified in this stage.

NOTES ON THE SPECIES..

***Culex (Lutzia) tigripes* Grandpré & Charmoy.**

An additional locality is Wad Arud.

***Culex (Barraudius) pusillus* Macquart.**

There are no new records.

***Culex*, subgenus *Neoculex*.**

Nine species were recorded from the Sudan by Lewis (1954). Mattingly (1955) has shown that *C. arbieeni* Salem occurs in Teneriffe and the Yemen as well as in the Sudan and Egypt. Larvae of this species from Jebel Marra have pale antennae (unlike Egyptian specimens), and the base and tip of the siphon and its valves with their setae and the valve levers are dark. The distal dorsal tufts of the siphon are rather thick and not unlike the spines found in this position in some other species. In the Sudan, *C. arbieeni* is only known from J. Marra. One young larva was found at Kelling and many old ones higher up the mountains at Kronga and Suni.

In a larva of *C. salisburyensis* Theo. from Suni the antenna is darker than in specimens from Eritrea or in those described by Hopkins (1952).

Mattingly (1953a) has redescribed the structures of the subapical lobe of the coxite of the male of *C. (N.) kingianus* Edw. from Congo and Sudan specimens. An additional record of this species is from Li Yubo, based on a mounted larva

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with a siphonal index of 13, of the form described by Mattingly (1953a) from Katanga specimens.

Culex, subgenus **Culiciomyia**.

The four Sudan species have previously been listed.

Culex (Culiciomyia) nebulosus Theobald.

Seven larvae, found in two water pots for pigeons at Tendelti on 27th and 29th August 1953 (A.T.), are provisionally regarded as aberrant or malformed specimens of *C. nebulosus* or perhaps a hybrid between this species and *C. cinereus* Theo., although Peters (1955) thinks they are a distinct form. Very many *C. nebulosus* have been examined in the northern Sudan without such

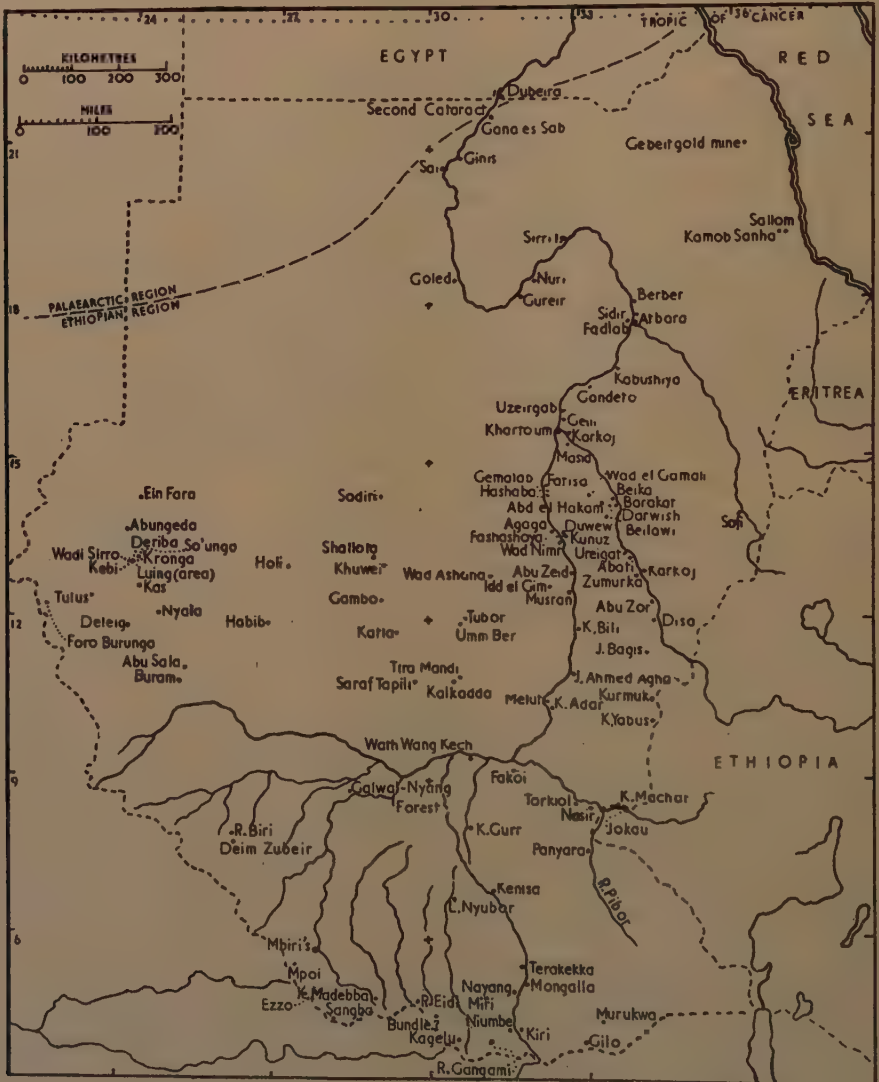


Fig. 1.—Map of the Sudan, showing places mentioned in the text, except some of those shown in previously published maps.

abnormalities being encountered and the existence of a distinct form near the middle of the area seems unlikely. The Tendelti larvae differ from those described by Hopkins (1952) as follows:—

Position of antennal tuft variable. Comb of about 25, or more than 30, short scales of variable size on a few of which one or more denticles may be replaced by spines. Siphon index about 2. Pecten of 4 to 6 teeth, 2 or more of which may be close together; each tooth with about 5 to 7 strong denticles. Upper caudal seta sometimes malformed.

It should be noted that some Sudan larvae which appear to be *C. nebulosus* do not agree closely with Hopkins' (1952) description; for instance the antennal tuft is often at the centre of the antenna, seta *f* can be single, and the pecten can have 11 spines.

Ezzo, Kosti, Li Yubo, Salima and Umm Koweika are additional localities of *C. nebulosus*.

Culex (Culiciomyia) cinereus Theobald.

Maridi and Mpoi are additional localities.

Culex, subgenus **Mochthogenes**.

There are no new records of the two species known in the Sudan.

Culex (Culex) poicilipes (Theobald).

Additional records are from Abati (O.M.), Abdel Hakim, Abu Hugar, Abu Haraz, Abu Tong, Abu Zeid, Abwong, K. Adar, Adok, Agaga, Ajwong, Akobo,

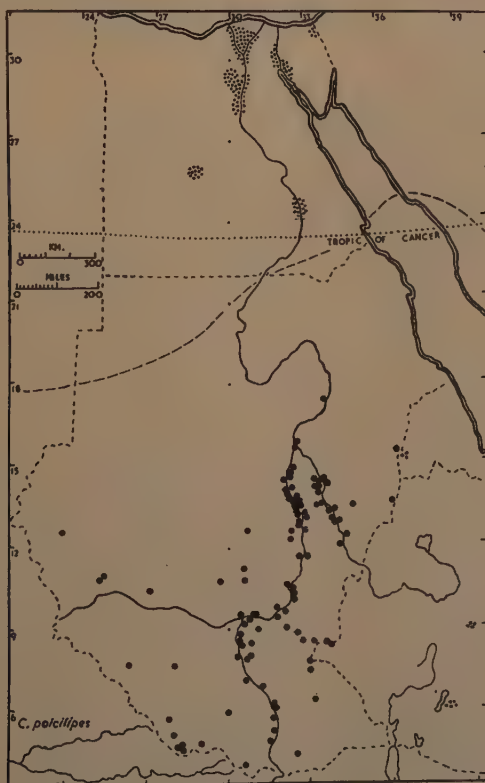


Fig. 2.

Bahr el Jebel km. 120, 182, Bakht er Ruda, Beilawi, Biri, Bor, Buffalo Cape, Danagla, Darwish, Dingba, Disa, Dubeiba, J. Dud, Dueim, Duweiwa, Fangak, Fashashoya, Fatisa, Gemalab, Geteina, Guli, Hag Abdullah, Hashaba, Heiban, Idd el Gim (*W.R.*), Jebelein, Jokau (*J.F.E.B.*), Juba, Kagelu, Kaka, Kassala, Kawa, Keilak, Kenisa, Kereida, Keri Kera, Kosti, Kunuz, Lado, Li Rangu, Lul, K. Machar (*J.F.E.B.*), K. Madebba, Maiurno, Malakal, Malek, Mbiri, Mellaha, Melut, Musran, Mvolo, Nasir, L. No, L. Nyubor (*E.T.M.R.*), Nzara (*P.H.A.*), Panamtin, Panyara, Pibor (*J.F.E.B.*), Rabak, Rahad, Renk, Riad, Er Ruat, Sennar, Shabak, Shambe, Shawal, Singa (*W.R.*), R. Sobat (middle), Suki, Suweilik, Tawila, Tiptiap, Tira Mandi, Tombe, Tonga, Torit (Hoogstraal, Huff & Lawless, 1950), Torkiol, Umm Jerr, Umm Shoka, Umm Sunt, Ureigat, Uzeirgab, Wad el Gamal, Wad el Magdub, Wad Nimr, Wath Wang Kech, Wau (*P.H.A.*), Yambio, Zeidab, Zeinuba, Bahr el Zeraf km. 121, 190, Zuleita and Zumurka.

Culex (Culex) bitaeniorhynchus Giles.

No new localities have been found.

Culex (Culex) ethiopicus Edwards.

Additional localities are Beika, Kas, Katla, El Liri, Malha, Maridi, Wad Ashana and Zeidab.

Most of the following records are based on larvae and some may possibly refer to one of the other two members of the *bitaeniorhynchus* group. Agur, Buffalo Cape, Basunda, Chunger, Dingba, R. Gangami, Gurein, K. Gurr, Jebelein, Juba, Kajo Kaji, Kenisa, Keri Kera, Kodi, Kodok, Koma, Kurmuk, Maingbara, R. Mayuku, Nzara, Rahad, Rejaf, R. Sobat (middle and lower), Tira Mandi, Yambio. Zalingei area and Zuleita.

Culex (Culex) annulioris Theobald.

Specimens of this species or forms intermediate between it and ssp. *consimilis* Newst. have been found at Kagelu, Katire, Li Rangu, Tembura, Wau (*P.H.A.*)

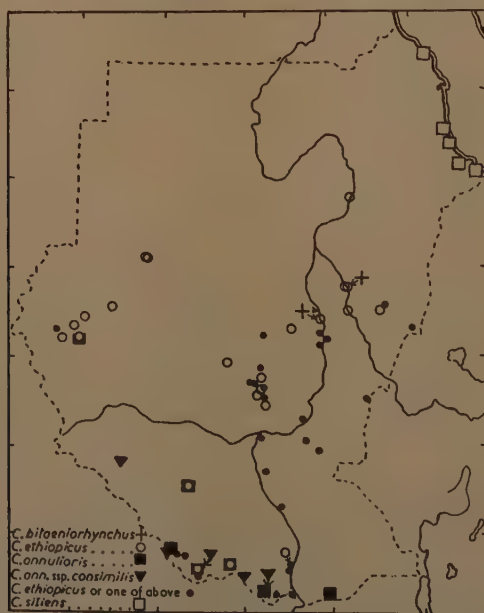


Fig. 3

and Yei. Edwards (1941) notes that a Maridi specimen is intermediate between the type form and the West African ssp. *consimilis*.

Culex (Culex) annulioris ssp. *consimilis* Newstead.

New records are from Kagelu, Li Rangu, Li Yubo and Raga.

Culex (Culex) sitiens Wiedemann.

The Sudan form, whose larva has a long siphon, is referred to by Hopkins (1952) as a variety described but not named. Long-siphon larvae have been found in Eritrea by Jannone, Ferro-Luzzi & Mara (1946) who state that the adults bite voraciously there.

New records are from Aqiq and Halaib (T.D.).

Culex (Culex) duttoni Theobald.

Additional localities are Abbasiya (I.A.), Abu Gubeiha (A.T.), Adok, K. Barboi, Bentiu, Bili, Buffalo Cape, Dilling, Ghulfan, Heiban, Juba (A.M.B.), Kadugli, Kalkadda, Kiri, Kologi, Li Rangu, El Liri, Li Yubo, Malakal, Maridi, Mellit, Mvolo, Nyala (A.T.), Nzara, Rashad, Sheikh Karim, Talodi, Tira Mandi, Tonga, Torit, Umm Ber, Umm Dorein, Wau, Weigo, Yambio and Yei.

Larvae are found in wells in Darfur during the dry season.

Culex (Culex) argenteopunctatus ssp. *kingi* (Theobald).

Larvae were recorded as an undetermined species by Lewis (1945, p. 15). Additional localities are Juba, Mvolo, Nzara, Sennar and Bahr el Zeraf km. 46.



Fig. 4.

Culex (Culex) theileri Theobald.

In larvae from J. Marra, head-seta B is usually double, but occasionally single or triple, and C is usually triple, but occasionally double or quadruple. In larvae from the Wadi Halfa area, B is often double and C sometimes has five branches.

New localities are Deriba (bred from puddles in crater of J. Marra), Gana es Sab (A.T.), Ginis and Sirri I. (A.K.A.), Suni and the Second Cataract.

Culex (Culex) univittatus Theobald.

Both the typical form and form *peregrinus* Theo. occur.

In some larvae, believed to be *C. univittatus*, most of the pecten spines have two secondary denticles, and one or more have three but not more. Such larvae must be carefully distinguished from *C. perfuscus* Edw.

C. univittatus is the commonest and most widely distributed Culicine in the Sudan, but is scarcely ever found biting man. Its numerous known localities are shown in fig. 5, but not listed. It occurs in almost every part of the Sudan except the desert, but in the extreme south-west and near the coast it is less common than elsewhere.

Mattingly (1954) has discussed the distribution of the type form, form *peregrinus* and intermediates, and the possibility of their being climatypes. The type form occurs in central Africa and form *peregrinus* in the Sudanese Savannah District and North Africa. The known distribution of these forms in the Sudan, based on the examination of the terminalia of one, or occasionally two, males from each place, is shown in fig. 6. Some of the southern localities are as follows: type form: Bor, Juba, Kadugli, Malakal, Maridi, Sennar, Talodi, Tiptip and Yei; intermediate: Abu Hugar, Agur, Delami, Deriba and Nasir; form *peregrinus*: Galwal-Nyang Forest, Nyala, Sennar, Sueilik, Tonga, and Wau. A few specimens were difficult to place as between intermediates and *peregrinus*.

Culex (Culex) univittatus var. **neavei** Theobald.

Additional localities are Abu Zor, Adok, J. Ahmed Agha, Bor, Geteina, Nasir, Shambe and Tendelti.



Fig. 5.



Fig. 6.

Culex (Culex) simpsoni Theobald.

According to Hopkins (1952) and Mattingly (1953a) the pecten teeth of the larvae can have several denticles. It therefore closely resembles the larva of *C. sinaiticus* Kirkpatrick which tends to breed in the same type of water. Males of *C. simpsoni* are available from Ein Fara, Gallabat, Heiban, Kajo Kaji, Mvolo, Niertete, Suni, Umm Berembeita (W.R.), Wad Arud, Wadi Sirro, Zalingei and Zumurka. Larvae of this species or *C. sinaiticus* have been found at Abungeda, Aqiq, Damasin, El Fasher, Foro Burunga (A.T.), K. Ganzi, Geneina, Ghulfan, Guldo, K. Gwob, Kalokitting, Katire, Kebi, Koma, Kronga, Kurmuk, Meidob, Mellit, Port Sudan, Roseires, So'unga and K. Yabus, and also at Mecca, Arabia (M.A.F.). Observations on *C. sinaiticus* mentioned by Lewis (1949) refer to *C. simpsoni*.

Culex (Culex) sinaiticus Kirkpatrick.

In some specimens the mesonotal integument is rather dark, and many dark, as well as pale, scales are present on the venter of the abdomen.

Kirkpatrick (1925), who described this species in 1924, reported that it occurred in the Sinai peninsula and bit at night. Edwards (1941) included it in the Ethiopian Region owing to its occurrence near the Red Sea coast of the Region, and reported it from Jebelain where there is a rocky hill. Lewis (1943) found that it was common in Eritrea. It now appears to be more widely distributed in the northern Sudan than in Egypt. Males are known from K. Arbaat, Erkowit, Gebeit Gold Mine, Kamob Sanha and Port Sudan. Larval records which may refer to this species or *C. simpsoni* are listed above under the latter.

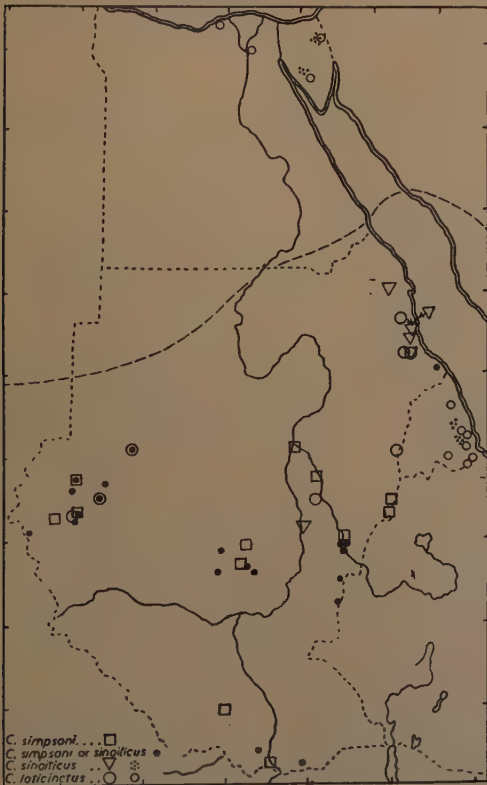


Fig. 7.



Fig. 8.

Culex (Culex) laticinctus Edwards.

Records of breeding places in the Sudan and Eritrea are listed here because they throw light on some interesting features of the distribution of this species. The larvae are easily recognised, yet they have been found in remarkably few localities in the Sudan. In a few suitable places, however, they were numerous. In both countries they have been found in both clean and dirty water and in company with a variety of other species.

Sudan: Ein Fara, pool in stream; K. Arbaat, a well and five places in a stream; Erkowit, a well and four pools in a stream; El Fasher, a jar; Khatmiya, a well; Luing, a jar and three rock pools; Malha, a rock pool; J. Moya, a pool in a deep rock cleft; Sinkat, a jar and five wells.

Eritrea: Addi Caieh, a tank and four pools in a stream; Addi Ugri, a drain; R. Macalo, a pool; Massawa, a well; Nacfa, a garden pool, a well, a barrel and a stream; Nefasit, two barrels; Sabur, a tank; Senafe, a tank.

Of the nine Sudan localities, six showed natural and six showed artificial breeding places. In the eight Eritrean localities three showed natural and ten showed artificial breeding places.

C. laticinctus extends far into Europe (Séguy, 1924) and is common in some Mediterranean countries. In the Sudan it is a distinctly northern species, yet it is also found in Kenya, in the Nairobi area (Mattingly, 1954).

In Lower Egypt, Kirkpatrick (1925) found a few localities of this species, chiefly with artificial breeding places, and was evidently surprised to find it in a certain isolated area and believed that its larvae might sometimes be transported in water skins. In the Sudan, localities are correspondingly few and, to judge by natural breeding places, the species is a rare relict confined to a few rocky hills, not necessarily high. Its ability to breed in wells and in deep rock clefts (Lewis, 1937) may enable it to survive at the lower altitudes. Its occurrence in dry areas where a single pool can be an important source of water for man makes it particularly liable to be spread by travellers. Its readiness to breed in artificial containers, however, does not generally seem to increase its distribution to a great distance.

Mattingly (1954) discussed the relation of *C. laticinctus* to a plutonic group of mosquitos and considers that, as a species of arid or semi-arid country, it must often be obliged to breed in warm water with a high mineral salt content. In the Sudan, however, its larvae are usually found in situations, described above, where the water is doubtless fresh and particularly cool; and it has never been found in saline pools although many larvae of other species have been obtained in them.

The distribution of *C. laticinctus* remains something of a puzzle in the Sudan. It has only once been found at J. Moya and never in the Nuba hills; though it does occur on J. Marra it has not been found in any of the streams examined there in the dry season.

Culex (Culex) pipiens Linnaeus.

Under this heading are included all specimens of the *pipiens* complex other than ssp. *fatigans* Wied. *C. pipiens* is a holarctic mosquito with isolated populations in the cooler parts of Africa (Mattingly, 1953a, b) and is regarded as a *pipiens-molestus* complex, an assemblage of diverse genetical potentialities (Mattingly & others, 1951). Possibly two forms occur in some parts of Africa, true *pipiens* and form *molestus* Forsk. (Hopkins, 1952, p. 302), or forms related to them. Extensive morphological and biological studies are necessary fully to assess the taxonomic status of a population. These have not been carried out in the Sudan, but some observations are recorded below which suggest the affinities of the Sudan forms in the light of the review of *C. pipiens* by Mattingly & others (1951). Specimens from two areas are considered separately because these have probably long been ecologically separate from each other.

Specimens from the Jebel Marra area.

Some observations.—Notes on a few adults were given by Lewis (1945). The average siphon index in ten batches of larvae (Table I) ranged from 5.1 to 6.4, and in one larva in another batch from Suni it was 7.3. From these figures and the inspection of many old, mounted, larvae it was obvious that the average

TABLE I.

The siphon indices in some collections of larvae of *Culex pipiens*.

Place	No. of larvae	Min.	Max.	Mean
Jebel Marra				
Deriba	7	6.4	6.9	6.4
Luing	15	5.4	6.5	5.9
"	8	5.8	6.6	6.2
"	22	5.5	6.5	5.9
"	8	5.5	6.4	5.9
"	20	5.0	6.5	5.8
"	8	5.4	5.8	5.6
"	20	5.3	6.4	5.9
"	8	5.6	6.0	5.8
"	8	4.9	5.2	5.1
Lowlands				
Kabushiya	7	4.5	5.1	4.6
Khartoum North	9	4.5	5.4	4.9
Various places (Lewis, 1945)	138	3.5	5.3	4.3

siphon index was higher than in *C. pipiens* from the lowlands. The ventral valve and valve lever are like those of the type form. Some of the hair tufts of the siphon tend to be long and thick. In 20 larvae from J. Marra and 4 from Zalingei, 16 and 3 larvae, respectively, had one or more tufts with thick branches about 3.3 to 5.3 microns in diameter. In a larva from Zalingei, some setae were longer than thrice the diameter of the siphon at the point of attachment, giving the larva the appearance of a different species. Length and thickness of setae seemed to be associated with a small number of branches, and further observations were made on this number which is a character more readily measured.

The number of branches in the siphon hair tufts, unlike the siphon index, can be readily observed in old mounted larvae. The tufts are sometimes described as being subventral but, although three pairs are subventral, there are usually also (Callot, 1938) one or two lateral or more or less dorsal tufts, not in a pair and shorter than the subventral ones. In the present work the number recorded was the number of branches of the four tufts of the side uppermost in the specimen examined, unless one of these tufts was missing. In some of the lowland specimens, as in those from Egypt (Knight & Abdel Malek, 1951), there were five pairs of tufts. In such cases the total number of branches was divided by five and multiplied by four. The number of branches in larvae from the Marra area is shown in Table II. The average number was 10.0, and, in contrast to the lowlands, the maximum was only 16 and no larvae had a fifth tuft.

In several larvae the anal papillae were rather long, occasionally twice the length of the ninth segment.

On J. Marra, *C. pipiens* breeds under rural conditions near or far from villages and at a considerable altitude. Deriba, in the crater, is uninhabited and is believed to be about 2,300 metres above sea-level. The climate of the mountains has scarcely been studied, but the writer observed a temperature of $-6^{\circ}\text{C}.$ at

Deriba in January 1954. During this visit a few males were seen and some larvae were collected, with many of *Theobaldia longiareolata* (Macq.), in the lake. None was found elsewhere on the mountain and the species is evidently restricted in its breeding places. The females have not been seen to bite by any of the three collectors who obtained this species.

TABLE II.

The number of branches in the siphon seta tufts in some collections of larvae of *Culex pipiens*.

Place	Min. no. of collections	No. of larvae	Total number of branches			Larvae with fifth tuft or pair
			Min.	Max.	Mean	
Jebel Marra area						
Deriba	2	5	8	12	9.6	0
Kronga	1	1	—	—	9.0	0
Luing*	1	16	8	16	10.4	0
"	1	8	8	13	10.4	0
"	4	7	10	13	11.7	0
"	1	6	8	12	10.0	0
J. Marra*	1	1	—	—	9.0	0
Suni area	1	33	8	14	10.4	0
Zalingei	1	4	8	11	9.5	0
		81	8	16	10.0†	0
Lowlands						
Hasiheisa	1	3	8	11	9.5	0
Juba	1	16	11	22	16.3	2
Kabushiya	1	7	9	18	13.7	1
Karkoj (near Khartoum)	1	17	10	21	13.2	0
Khartoum	1	9	10	22	14.3	0
Khartoum North	1	8	9	15	12.6	2
Kodok	1	6	10	17	13.7	0
El Obeid	1	16	11	23	15.4	2
Omdurman	1	18	12	18	14.8	0
"	1	7	12	19	14.4	0
"	1	7	11	16	13.1	0
Shambat	1	19	10	14	11.5	0
Wadi Halfa	1	9	9	18	13.3	1
"	1	14	10	19	12.9	4
"	4	12	9	18	12.8	1
		169	8	23	14.1†	13

For larvae with an extra pair of tufts the number has been adjusted.

* Area names signifying separate collections possibly from Kronga or Deriba.

† Unweighted means.

Identity.—Before discussing the identity of the Marra *C. pipiens* it is appropriate to refer to the number of branches of the siphon hair tufts as a character for members of the *C. pipiens* complex. Knight (in Mattingly & others, 1951) points out that this number has been extensively used but that it seems to be more indicative of local populations than of anything else. Marshall & Staley (1937, pp. 25, 26) and Marshall (1938) found considerable variation and overlap and a lower number, 9.7, in *C. pipiens* than the 12.0 in form *molestus*. Jobling's (1938) average numbers were 10.7 and 11.6, respectively. Callot (1947) considered that the larval chaetogram was associated with biological differences.

Knight & Abdel Malek (1951) found an average number of 13 in the Cairo *molestus*. The number of branches may generally have very little value in classifying populations, but it is interesting to find that in the Sudan, out of two populations, one shows a very low tuft number and other features which suggest that it may be the type form. These features of the Marra population are its occurrence in a high, relatively cool area partly subject to frost, rural breeding habits, a possible reluctance or refusal to bite man, and the possession of a long siphon. It is possible, however, that the Marra *pipiens* is only a local form or a climatype.

Distribution.—Larvae have been obtained from pools at Deriba, Kronga, Luing (the area around Kronga) and Suni, and from a well at Zalingei. Kronga and Suni are 23 km. apart, on opposite slopes of the mountain, and 8 and 17 km., respectively, from Deriba. Zalingei is 42 km. west of Deriba and about 1,000 metres above sea-level. All these localities are separated from those of the lowland *C. pipiens* by semi-desert country untraversed by a railway or made road.

Specimens from the lowlands.

Some observations.—Several characters of the adult and larvae have been described by Lewis (1945), and recent measurements of siphons are shown in Table I. The mean siphon index ranges from 3.7 to 4.9 in nine batches examined. The valve lever is shorter than in Marra larvae and varies in appearance mainly owing to differences in the siphon index. In 20 larvae from various places, only four had thick setae in the siphonal tufts. Most setae were only about 2.6 microns in diameter.

The average number of branches in the siphonal tufts (shown in Table II) was 14.1, and the averages from different localities showed little overlapping with the *C. pipiens* from J. Marra. The maximum number of branches was higher in *C. pipiens* from the Nile valley, and 8 per cent. of the latter bore an extra tuft.

At Omdurman and Wadi Halfa, *C. pipiens* bites man, and at Omdurman it often breeds in pit latrines and wells. A single attempt was made to breed from a few *C. pipiens* from Wad Medani in a cage without a blood-meal. No eggs were laid, but Knight & Abdel Malek (1951) found that few Cairo *molestus* would oviposit autogenously.

Identity.—*C. pipiens* may occur in Egypt as well as form *molestus* (Knight & Abdel Malek, 1951), and the same is true of the Sudan lowlands which adjoin Egypt. In the Sudan lowland *C. pipiens* the presence of many larvae with a short siphon, the high average number of branches in the siphon tufts (near the Cairo figure), the rather urban distribution, the presence of many larvae in latrines, and the tendency to bite man suggest that all or most of the lowland *pipiens* are form *molestus*.

Distribution.—The lowland form of *C. pipiens* is found at several places between Omdurman and Wadi Halfa, and is believed to have been spread by steamers up the White Nile, and by train to several other lowland places near the Nile and to the coastal area. Khalil (1938) attributed the spotted distribution of *Wuchereria bancrofti* in Egypt to the fact that *C. pipiens* breeds mainly in wells. According to Farid (1949) it flourishes in winter and breeds in cool underground water. In some of its Sudan localities it has only been found during special inspections of wells.

Additional localities are Abri, Abu Ushar, Adok, Atbara, Berber, Dubeira, Erkowit, Fadlab, Geili, Goled, Gureir, Juba, Kabushiya, Kadar, Kodok (A.K.A.), Li Yubo (A.T., larvae with short siphon and many branches in tufts), Merowe, Nuri, El Obeid (A.T.), Omdurman (A.A.M.), Port Sudan (few), Shambat, Sidir (A.A.B.), Wadi Seidna, Wad Medani (once found biting), and Zeidab. Some records are from steamers (fig. 8), and Tombe may be one of

these. Several localities for lowland *C. pipiens* are based on larvae, but terminalia of many males from Omdurman, Wad Medani, Wadi Halfa and various places other than Li Yubo have been examined, and it is believed that in fig. 8 there is no confusion between *C. pipiens* and ssp. *fatigans*.

Old records under the name of *C. fatigans* from Khartoum probably refer to *C. pipiens* which has been under control there for many years. Balfour (1904*a, b*) reported that "*C. fatigans*" was abundant, and was very numerous and annoying at the Grand Hotel where it was found breeding in a well.

***Culex (Culex) pipiens* ssp. *fatigans* Wiedemann.**

This mosquito is now recognised to be a subspecies of *C. pipiens*, which hybridises with it to a significant extent in nature (Mattingly, 1953*b*). In the Sudan there is little opportunity for hybridisation.

C. p. fatigans has been described as "cosmotropical" and as being found "almost everywhere in the tropics" and "throughout the tropical and subtropical regions". In the vast extent of the Sudan, however, it is only known from a comparatively small area near the coast where it may have been introduced by shipping. It seems probable that *C. p. fatigans* has acquired its wide tropical distribution largely by association with man, but in the Sudan it has apparently failed to penetrate far inland across the desert by rail. It may have reached Kassala by road from Eritrea.

Additional localities are Gebeit Gold Mine (T.D.), Halaib, Sallom (breeding in pit latrine, G.M.R.) and Tokar. A few years ago *C. p. fatigans* multiplied at Port Sudan owing to the increased use of septic tanks there.

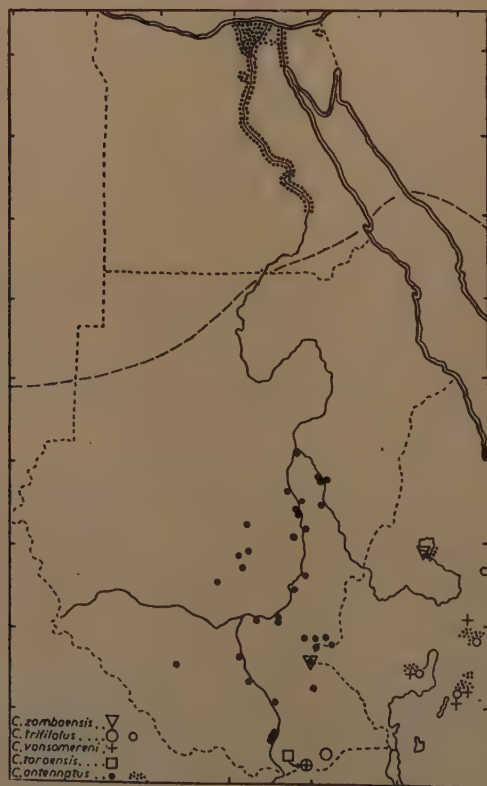


Fig. 9.

Culex (Culex) zombaensis Theobald.

Males have been found at Akobo (*J.F.E.B.*).

Culex (Culex) triflatus Edwards.

The type form of this species is known from Gilo, Katire and Nagishot, which are in the mountains near the southern frontier.

Culex (Culex) vansomereni Edwards.

This species, or possibly a subspecies, is only known from larvae from Gilo. There are about 35 comb spines. The siphon is pale and in the one measured the index is 5. The pecten is very variable. Most of the spines have denticles along most of their length; the distal spines are simple or denticulate. In some larvae there is one spine between the pecten and the coronet and in others there are several spines making the pecten almost continuous with the coronet.

Culex (Culex) toroensis Edwards & Gibbins.

Edwards (1941, p. 434) has described variations of what Hopkins (1952) calls the "excessively variable larva" of this species.

The only Sudan specimens known are 12 aberrant larvae from Gilo. In most of the 12 examined the siphon is bent upwards near the tip. The pecten may be more or less than half the length of the siphon and consists of 14 to 17 pairs of spines, the distal ones sometimes not opposite each other. In seven larvae there is an unpaired spine, medio-ventral except in one case where it is dorsal and near the tip; in other larvae the distance from the tip is variable.

Culex (Culex) antennatus (Becker).

Additional localities are Adok, Agaga, J. Ahmed Agha, Akobo, K. Barboi, Beika, Fakoi, Fashishoya, Jokau and K. Machar (*J.F.E.B.*), Melut, Nasir, Nayang, Pibor and Pibor mouth (*J.F.E.B.*), Er Ruat (*W.R.*), Torkiol, Wad Medani, and Wau (*P.H.A.*).

Culex (Culex) decens Theobald.

Most of the following additional records are based on findings of larvae and a few may possibly refer to *C. invidiosus* Theo.: Abri, Abu Hugar, Abu Tong, Adok, Aga Falls, Agur, Amadi (*W.R.*), J. Bagis, Barakat, Basunda, Bor, R. Eidi, Gilo, Heiban, Iyal Bakhit, Jelelein, Juba, Kagelu, Kajo Kaji (*W.R.*), Kalkadda, Kapoeta, Kas, Katla, Kerripi, Khuwei (*N.M.G.*), Lado, Li Rangu, El Liri, Maingbara, Malakal, Masakin, J. Moya, Murukwa, Mvolo (tree hole), L. Nyubor (*E.T.M.R.*), Nzara (*P.H.A.*), Shalota, Sheikh Karim, Singa, Sodiri, Sofi, Suki, Suqa el Gamal, Tembura, Terakekka, Tira Mandi, Tonga, Torit, Tubor, Wad Medani, Wau (*P.H.A.*), Yambio, Zeinuba and Bahr el Zeraf km. 46. Edwards' (1941) Zeidab record perhaps requires confirmation.

Culex (Culex) invidiosus Theobald.

There are no new records.

Culex (Culex) trifoliatus Edwards.

There are no new records.

Culex (Culex) perfuscus Edwards.

New records are from Gurein, Heiban, Maingbara, Malakal, Rahad, Sennar, Tubor, Umm Berembeita and Wad Medani.

Culex (Culex) guiarti Blanchard.

New localities are Bandula, Mvolo, Nzara and Yambio.

Culex (Culex) weschei Edwards.

The only Sudan records are of larvae from Gambo, Habib and Talodi.

Culex (Culex) ingrami Edwards.

In a larva of the Uganda form from Nzara (P.H.A.) the index of the mounted siphon is about 7. The following figures show the positions and numbers of the spines of the siphon. The decimals are fractions of the siphon and show the



Fig. 10.



Fig. 11.

distance between its base and the bases of the spines: 0 to 0.29, 12 pairs of spines, the basal ones slightly barbed, the distal ones simple; 0.35 to 0.61, 4 pairs of spines not opposite each other; 0.69, 0.83 and 0.87, 3 unpaired nearly mid-ventral spines; 0.94 to 0.96, 2 pairs of appressed spines.

Culex (Culex) grahami Theobald.

New localities are Li Rangu, Mvolo and Sangba (P.H.A.).

Culex (Culex) pruina Theobald.

Larvae have been found in a water jar at Yambio (A.T.).

Culex (Culex) moucheti Evans.

Two larvae were found, with several of *C. nebulosus*, in a domestic water jar at Yambio in September 1954 (A.T.).

DISCUSSION ON FEATURES OF THE FAUNA.

Composition of the Fauna.

Mosquitos of the genus *Culex* in the Sudan comprise 45 species, two sub-species and one variety.

Species common to the Ethiopian and other regions.

Edwards (1941, p. 450) shows that, of the species of the genus *Culex* that occur in the Ethiopian Region, a number is also found in other zoogeographical regions. The Sudan, as one would expect from its position, has a high proportion of such species.

Four of the six species listed by Edwards as being common to the Ethiopian and Oriental Regions occur in the Sudan. *C. bitaeniorhynchus*, which is widespread in India (Barraud, 1934), has only a very limited distribution in the Sudan and has probably spread from East Africa. *C. sitiens* is confined to the coast. *C. theileri* is very localised in the Sudan, *C. univittatus* is very widely distributed, and *C. pipiens* has a rather wide distribution although ssp. *fatigans* is almost confined to the coast, where it was probably introduced in historical times.

Edwards lists nine species as being common to the Ethiopian and Palaearctic Regions. Of these, *fatigans* is to be omitted, being a subspecies, and *C. arbieeni* added. Of the 12 Egyptian species of *Culex* only three, *C. (Lasiosiphon) adairi* Kirkpatrick (of which *C. pluvialis* Kirkp. is a synonym according to Kirkpatrick, 1927), *C. tritaeniorhynchus* Giles and *C. deserticola* Kirkpatrick are not known in the Sudan, although Edwards (1941) expected that *C. adairi* and *C. deserticola* might be found in the Ethiopian Region and *C. tritaeniorhynchus* does occur in some other parts of it.

C. arbieeni is known from J. Marra and three areas outside the Sudan.

Two species have spread from the Ethiopian into the Palaearctic Region; *C. poicilipes* extends discontinuously down the Nile to Alexandria, but not farther into the Mediterranean area (Edwards, 1921), and *C. antennatus* is "probably the most abundant Egyptian mosquito" and extends on into Palestine (Kirkpatrick, 1925). The latter species, like various others, is particularly numerous near the limit of its range.

The distribution of *C. univittatus* form *peregrinus* in the Sudan perhaps suggests that it is not a climatype but a northern form which has penetrated far to the south. The distribution of the type form shows little relation to rainfall but suggests the presence of relict populations in the Nuba Hills and perhaps the Marra mountains.

C. sinaiticus does not penetrate far south. *C. laticinctus*, as shown above, occurs in a few scattered places and does not spread easily.

Edwards (1941, pp. 455, 462) discussed the origin of the type form of *C. pipiens* in the Ethiopian Region. He considered that the presence of numerous species of the *pipiens* series in the Humid Montane Province suggested some connection with the temperate north, and considered that *C. pipiens* (and *C. theileri*) might have invaded South Africa from Europe by way of the eastern highlands. In this connection the finding of both these species on J. Marra is interesting since they have almost certainly been there for thousands of years and the massif is one of several lying between the Sudan and the Atlas Mountains. It may be that *C. pipiens* spread southwards by way of the central Saharan mountains and the Red Sea Hills in the pluvial periods and that the form *molestus* has been carried up the Nile valley by man much more recently.

In addition to species common to the Palaearctic and Ethiopian Regions there are several in one region which have a close relative in the other. *C. brumpti* Galliard is closely related to *C. zombaensis*, and *C. (Neoculex) deserticola* to *C. salisburyensis* (Mattingly, 1954), and also *C. sinaiticus* (fig. 7) to *C. simpsoni*. *C. sinaiticus* is known only from the Red Sea area, apart from Edwards's record from Jebelein.

Species of the subgenus *Culex*, unlike those of *Neoculex* and *Mochthogenes*, tend to be widely distributed in the Sudan. Among the exceptions are *C. trifilatus*, *C. vansomeri*, *C. toroensis*, *C. annulioris* ssp. *consimilis* and *C. pruina*.

Discontinuity.

Of the nine species common to Egypt and the Sudan, at least four show considerable discontinuity between the two countries. *C. arbieeni* is a remarkable example of this. *C. poicilipes* (fig. 2) does not occur throughout the length of the Nile to the delta as it is sometimes said to do, and neither it nor *C. antennatus* has ever been found in the Wadi Halfa area despite extensive surveys. *C. theileri* (fig. 4) in J. Marra and Eritrea is cut off by a great distance from its Egyptian and Wadi Halfa areas. Probably these gaps have developed with a drying climate, and it is likely that *C. poicilipes* and *C. antennatus* formerly occurred all along the Nile and *C. theileri* along the Red Sea Hills, and that *C. arbieeni* existed in many hills which are now dry.

Desert pallor.

Several members of the genus *Culex* in the Sudan show the tendency to pale colouring in arid lowland regions. Some examples were given by Lewis (1943, 1954). In *C. tigripes* there is apparently some tendency for a dark form to occur in the south. *C. ethiopicus* tends to be commoner in the north than darker related species, and the Red Sea form of *C. sitiens* is rather pale (Edwards, 1941). Edwards writes of a "remarkable aberration" of *C. duttoni* in the shape of "a female from El Fasher, Sudan, which has most of the abdominal scales flavescent". Of *C. theileri*, he writes: "As with many other species, specimens found in desert regions tend to be much paler than the normal." He describes a pale type of abdominal marking, which is seen at Wadi Halfa. Specimens from J. Marra and Eritrea, on the other hand, lack this coloration and have a dark integument. Darker specimens of *C. univittatus* are restricted to areas south of Khartoum. Some *C. simpsoni* on J. Marra have a very dark integument. *C. sinaiticus* and *C. laticinctus* are somewhat pale species restricted, in the Sudan, to rather dry areas.

Species widely distributed in the Sudan.

C. univittatus is unique in being almost ubiquitous. *C. tigripes*, *C. nebulosus*, *C. poicilipes*, *C. ethiopicus* and *C. decens* are very widely distributed. Less widespread are *C. duttoni*, *C. simpsoni* and *C. antennatus*. The absence of *C. duttoni* from the lower White Nile and the Gezira is remarkable and may be due to its tendency to breed in rocky pools or polluted water in swamps. The distribution of *C. pipiens* in the Nile valley is largely dependent on man-made breeding places.

IMPORTANCE AND RELATION TO DISEASE.

Principal Man-biting Species.

There are several species which commonly bite man in the Sudan. *C. poicilipes* and *C. antennatus* bite in vast numbers near many swamps. *C. pipiens* and *C. p. fatigans* bite man, particularly near houses, but their distribution—especially that of *fatigans*—is limited. *C. univittatus* var. *neavei* is sometimes found biting near its breeding places (Lewis, 1947).

Possible Relation to Human Disease.

Species of *Culex* may prove to have some relation to yellow fever in the Sudan, perhaps by transmitting it between individuals of some species of mammal during periods when no human cases are found. Lumsden & van Someren (1953) have drawn attention to *C. poicilipes* and *C. univittatus* var. *neavei* as being possibly concerned in the maintenance of yellow fever virus among wild monkeys during the dry season in Uganda.

West Nile virus has been reported from many parts of the Sudan by Smithburn & Jacobs (Lewis, 1953). It is now known to occur in Egypt and Israel, and *C. pipiens* and *C. antennatus* are suspected of being vectors (Davies & Yoshpe-Purer, 1954; East Africa High Commission, 1954). *C. antennatus* is common in only a few Sudan localities of the disease and other mosquitos occur in most of them.

C. pipiens is the vector of *Wuchereria bancrofti* in Egypt (Khalil, 1936, 1938; Salem, 1933) and *C. p. fatigans* in some other parts of Africa, but these forms are rare or absent in areas of the Sudan where the disease is known.

Summary.

Forty five species, two subspecies and one variety of *Culex* occur in the Sudan.

Taxonomic notes are given on a few species, and new localities, mainly for the subgenus *Culex*, are recorded. The known distribution of all species of this subgenus is shown on maps.

Several aspects of distribution are discussed, and there is a short section on practical importance.

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References.

- ABBOTT, P. H. (1948). The Culicidae (Diptera) of Darfur Province . . .—Proc. R. ent. Soc. Lond., (B) **17**, pp. 37–48.
- BALFOUR, A. (1904a). Notes on the tropical diseases common in the Anglo-Egyptian Sudan . . .—J. trop. Med., **7**, pp. 115–120.
- BALFOUR, A. (1904b). Mosquito work in Khartoum and in the Anglo-Egyptian Sudan generally.—1st Rep. Wellcome trop. Res. Lab., pp. 14–36.
- BARRAUD, P. J. (1934). The fauna of British India . . . Diptera. Vol. V. Family Culicidae. Tribes Megarhinini and Culicini.—463 pp. London, Taylor & Francis.
- CALLOT, J. (1938). Contribution à l'étude des moustiques de Tunisie et en particulier du sud de la régence.—Arch. Inst. Pasteur Tunis, **27**, pp. 133–183.
- CALLOT, J. (1947). Étude sur quelques souches de *Culex pipiens* (*sensu lato*) et sur leurs hybrides.—Ann. Parasit. hum. comp., **22**, pp. 380–393.
- DAVIES, A. M. & YOSHPE-PURER, Y. (1954). Observations on the biology of West Nile virus, with special reference to its behaviour in the mosquito *Aedes aegypti*.—Ann. trop. Med. Parasit., **48**, pp. 46–54.
- EAST AFRICA HIGH COMMISSION (1954). Virus Research Institute. Annual report 1953.—Nairobi.
- EDWARDS, F. W. (1921). A revision of the mosquitos of the Palaearctic Region.—Bull. ent. Res., **12**, pp. 263–351.

- EDWARDS, F. W. (1941). Mosquitoes of the Ethiopian Region. III. Culicine adults and pupae.—499 pp. London, Brit. Mus. (Nat. Hist.).
- FARID, M. A. (1949). Relationships between certain populations of *Culex pipiens* Linnaeus and *Culex quinquefasciatus* Say in the United States.—Amer. J. Hyg., **49**, pp. 83–100.
- HOOGSTRAAL, H., HUFF, C. G. & LAWLESS, D. K. (1950). A malarial parasite of the African elephant shrew, *Elephantulus rufescens dundasi* Dollman.—J. nat. Malar. Soc., **9**, pp. 293–306.
- HOPKINS, G. H. E. (1952). Mosquitoes of the Ethiopian Region. I. Larval bionomics of mosquitos and taxonomy of Culicine larvae.—2nd edn., 355 pp. London, Brit. Mus. (Nat. Hist.).
- JANNONE, G., FERRO-LUZZI, G. & MARA, L. (1946). Risultati di una spedizione tecnico-scientifica nella Dancalia Settentrionale Esterna.—Boll. Soc. ital. Med. (Sez. Eritrea), Monogr. no. 2, 167 pp.
- JOBLING, B. (1938). On two subspecies of *Culex pipiens* L. (Diptera).—Trans. R. ent. Soc. Lond., **87**, pp. 193–216.
- KHALIL, M. (1936). Filariasis and elephantiasis in Rossetta and the means of their effective control.—J. Egypt. med. Ass., **19**, pp. 701–716.
- KHALIL, M. (1938). The life-history of *Wuchereria bancrofti* in Egypt, its pathogenicity and control . . .—Acta Conv. ter. trop. Malar. Morb., **1**, pp. 258–271.
- KIRKPATRICK, T. W. (1925). The mosquitoes of Egypt.—224 pp. Cairo, Egypt. Govt. Anti-Malar. Comm.
- KIRKPATRICK, T. W. (1927). *Culex (Lasiosiphon) adairi*, nom. nov.—Bull. Soc. R. ent. Egypte, **19**, p. 112.
- KNIGHT, K. L. (1953). Two new species of mosquitoes from the Yemen (Diptera: Culicidae).—J. Wash. Acad. Sci., **43**, pp. 320–325.
- KNIGHT, K. L. & ABDEL MALEK, A. A. (1951). A morphological and biological study of *Culex pipiens* in the Cairo area of Egypt (Diptera—Culicidae).—Bull. Soc. Fouad Ier Ent., **35**, pp. 175–185.
- LEWIS, D. J. (1937). A new species of *Anopheles* from the Anglo-Egyptian Sudan.—Proc. R. ent. Soc. Lond., (B) **6**, pp. 181–183.
- LEWIS, D. J. (1943). The Culicine mosquitos of Eritrea.—Bull. ent. Res., **34**, pp. 279–285.
- LEWIS, D. J. (1945). Observations on the distribution and taxonomy of the Culicidae (Diptera) in the Sudan.—Trans. R. ent. Soc. Lond., **95**, pp. 1–24.
- LEWIS, D. J. (1947). General observations on mosquitos in relation to yellow fever in the Anglo-Egyptian Sudan.—Bull. ent. Res., **37**, pp. 543–566.
- LEWIS, D. J. (1949). Tracheal gills in some African Culicine mosquito larvae.—Proc. R. ent. Soc. Lond., (A) **24**, pp. 60–66.
- LEWIS, D. J. (1953). The *Stegomyia* mosquitoes of the Anglo-Egyptian Sudan.—Ann. trop. Med. Parasit., **47**, pp. 51–61.
- LEWIS, D. J. (1954). *Culex* mosquitoes of subgenera other than *Culex* in the Anglo-Egyptian Sudan.—Ann. Mag. nat. Hist., (12) **7**, pp. 7–12.
- LUMSDEN, W. H. R. & VAN SOMEREN, E. C. C. (1953). Records of *Culex* species (Diptera: Culicidae) from West Nile District, Uganda, with notes on their behaviour.—Proc. R. ent. Soc. Lond., (B) **22**, pp. 19–22.

- MARA, L. [1946]. Considerazioni sul rinvenimento dell' *Aedes aegypti* L. (Dip., Aedinae) ad altitudini d'eccezione e brevi note sulla fauna culicidica del M. Bizen (Eritrea, A.O).—Boll. Soc. ital. Med. (Sez. Eritrea), **5**, pp. 189–198.
- MARSHALL, J. F. (1938). The British mosquitoes.—341 pp. London, Brit. Mus. (Nat. Hist.).
- MARSHALL, J. F. & STALEY, J. (1937). Some notes regarding the morphological and biological differentiation of *Culex pipiens* Linnaeus and *Culex molestus* Forskål (Diptera, Culicidae).—Proc. R. ent. Soc. Lond., (A) **12**, pp. 17–26.
- MATTINGLY, P. F. (1953a). Notes on the Culicini of the Katanga (Diptera, Culicidae). Part I. Taxonomy.—Rev. Zool. Bot. afr., **47**, pp. 311–343.
- MATTINGLY, P. F. (1953b). The *Culex pipiens* complex.—Trans. IXth int. Congr. Ent., **2**, pp. 285–287.
- MATTINGLY, P. F. (1954). The distribution of some African mosquitoes.—Proc. Linn. Soc. Lond., **165**, pp. 49–61.
- MATTINGLY, P. F. (1955). Le sous-genre *Neoculex* (Diptera, Culicidae) dans la sous-région Méditerranéenne I. . . .—Ann. Parasit. hum. comp., **30**, pp. 374–388.
- MATTINGLY, P. F. & others. (1951). The *Culex pipiens* complex.—Trans. R. ent. Soc. Lond., **102**, pp. 331–382.
- PETERS, W. (1955). The mosquitoes of Liberia (Diptera: Culicidae).—Proc. R. ent. Soc. Lond., (B) **24**, pp. 81–90.
- SALEM, H. H. (1933). New records of some Egyptian mosquitoes.—Bull. Soc. R. ent. Égypte, **17**, pp. 83–92.
- SALEM, H. H. (1938). The mosquito fauna of Sinai Peninsula (Egypt) with a description of two new species.—Publ. Fac. Med. Egypt. Univ., no. 16, 32 pp.
- SÉGUY, E. (1924). Les moustiques de l'Afrique mineure, de l'Égypte et de la Syrie . . .—Encycl. ent., (A) **1**, 257 pp. Paris, Lechevalier.
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SOME MOSQUITOS OF THE SUDAN.

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The occurrence and distribution of members of the genera *Anopheles*, *Aedes* and *Culex* in the Sudan have already been considered in publications referred to below, and the main purpose of the present paper is to record the species of the other 11 genera of the CULICINAE. Their known distribution is shown in figs. 2 to 16, but the names in the distribution lists are only additional to those recorded by Edwards (1941) and Lewis (1945). Fig. 1 includes some place-names which are additional to those given by Lewis (1956a) and in papers referred to by him.

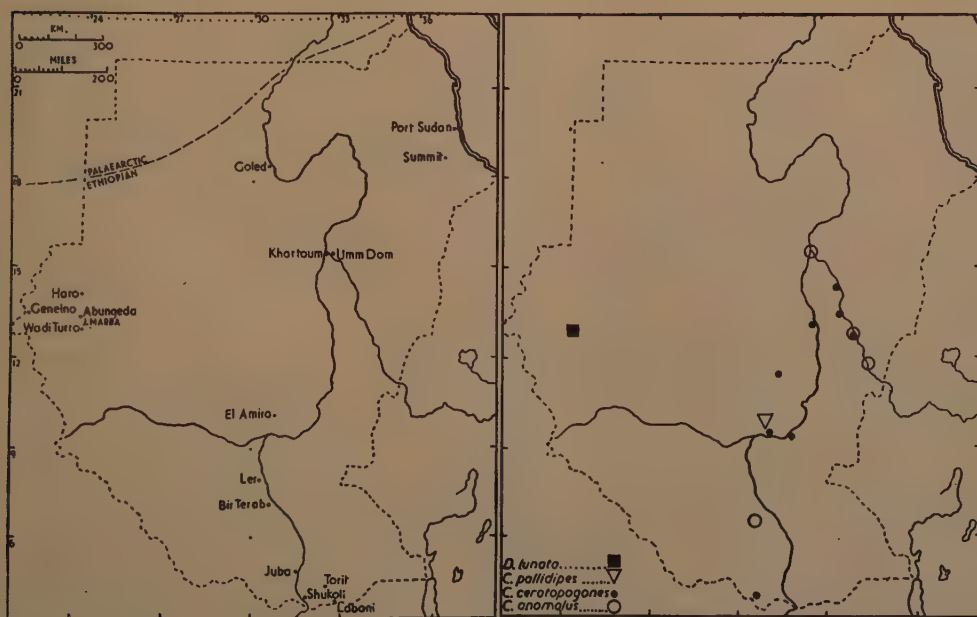


Fig. 1.—Map of the Sudan, showing some places mentioned in the text including those not shown by Lewis (1956a) or in previous papers.

Fig. 2.

The initials in brackets after certain records are those of collectors whose names are given in the acknowledgements section.

The taxonomic works of Edwards (1941), Gillett (1949), Hopkins (1952) and van Someren (1949) have been used for identification. Foote (1953) has published a key to a few species of mosquitos in the Sudan.

Occasionally larvae and adults of various species are seen which have an unusual appearance, probably due to malformation or to individual variation. They are usually easy to identify, however, because they are seen after the

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examination of many normal specimens. Examples among larvae of various species have been noticed with one or both antennae stump-like. Other abnormalities, not seen in the 11 genera under consideration, have been deformed comb-spines in *Aedes metallicus* (Edw.) and *Culex nebulosus* Theo., and a very long siphon or long siphon tufts in *C. pipiens* L. from Jebel Marra.

NOTES ON THE SPECIES.

DIXINAE.

Dixa lunata Edwards.

Three females of this species, which is only known from Nyasaland and Tanganyika (Mattingly, 1954), have been found near a waterfall at Kelling on J. Marra.

CHAOBORINAE.

Chaoborus (Sayomyia) pallidipes Theobald.

This species has only been found at El Amira (in December) and in a flying-boat from Port Bell. The members of this genus have not been specially studied in the Sudan and are doubtless more widespread than records show.

Chaoborus (Sayomyia) ceratopogones Theobald.

The known localities are Abu Gubeiha (bred from a domestic water jar), Abu Hugar, Hawata, Kagelu (many bred from shady pool in bed of stream), Khartoum (only in aircraft from Port Bell), Kosti, Malakal, Sennar, Tonga (bred from shallow grassy swamp), Umm Sunt (bred from flooded forest and from water left in snail shells there) and Wad el Magdub.

According to Edwards (1930), who gives 11 localities including several places away from lakes, this species is widely distributed throughout tropical Africa.

Chaoborus (Neochaoborus) anomalus Edwards.

Most specimens (including those from Yirol, as I am informed by Mr. P. Freeman) are paler than the type form.

The known localities are Dar Aqil (April), Khartoum, Roseires (December) and Yirol (*E.T.M.R.*, males and females, det. *P.F.*).

Edwards (1930) only gives two localities, Accra and Entebbe. In Lake Victoria, where this species has been studied (East Africa High Commission, 1952), the aquatic stages last for about two months, the first- and second-instar larvae are planktonic, and those of the third and fourth instars live in the mud by day and among the plankton at night. Two collections of *Ch. anomalus* consisted entirely of females and this was attributed to the emergence of the sexes at different times.

Apart from the Yirol record, the only known breeding place of this species in the Sudan is the Blue Nile, particularly in the dry season when the river flows very slowly and has some of the features of a lake. Fourth-stage *Chaoborus* larvae are commonly found at night in the Blue Nile plankton at Khartoum, and pupae of both sexes are sometimes seen. Adult females of *Ch. anomalus*, but no males, have been taken in a light trap in September, October (many on 15. and 17.x.53) and November. Lindquist, Roth & Walker (1951) found that most *Chaoborus* taken near the water's edge at Clear Lake, California, were females, so it may be that at Khartoum the males fly inland. It is presumed that the *Chaoborus* larvae found at Khartoum had drifted from far up the river.

CULICINAE: ANOPHELINI.

Twenty eight species and three varieties of Anophelines occur in the Sudan (Lewis, 1956a).

CULICINAE: TOXORHYNCHITINI.

Toxorhynchites brevipalpis ssp. **conradti** Grünberg.

In a male from Wau the abdomen is atypical, being purple-scaled above, although the absence of long hairs on the tarsus indicates that it belongs to this species, and a male from Mvolo is very similar. It may be that metallic colours are very variable as in some Calliphorid flies.

Adults have been found at Heiban, Li Rangu, Li Yubo, Mvolo, Torit and Wau (P.H.A.), and larvae at Ezzo and Yambio.



Fig. 3.



Fig. 4.

Toxorhynchites viridibasis (Edwards).

The three available adults are placed in this species although the abdominal tufts are more orange than red. Perhaps, as Edwards (1941) suggests, this mosquito is a subspecies of *T. lutescens* Theo.

The only known Sudan localities are Heiban, Er Ruf (larva, 10.viii.53) and Wad Medani (Umm Baruna wood). It is surprising that so few of the conspicuous larvae of this species have been found although thousands of mosquito larvae from tree holes have been examined. The Er Ruf larvae were found in an iron container with larvae of *Aë. metallicus*, one of which had just been eaten by a larva of *T. viridibasis*.

CULICINAE: CULICINI.

Harpagomyia taeniarostris Theobald.

No new localities have been found.

Harpagomyia sp.

In a larva from a banana axil at Wau (M.O.Z.) head-seta B has 2 branches on one side and three on the other, *e* and *f* are side by side, the seta behind *f* has four stout branches, the outer of which is swollen near its base, and the comb is composed of spines.

Hodgesia cyptopus Theobald.

A single female bred from a pupa found among recumbent grass at Malakal is probably of this species. In two larvae from Li Yubo (*P.H.A.*) the siphon has a distinct acus.

Uranotaenia pallidocephala Theobald.

Additional localities are R. Kobwa, Maridi (*W.R.*) and Shambe (*W.R.*).

Uranotaenia alboabdominalis Theobald.

Additional localities are L. Jur and Maridi.

Uranotaenia alba Theobald.

A larva from Ajwong is probably this species.

Uranotaenia bilineata var. **fraseri** Edwards.

Additional records, based on larvae, are from Aga Falls, Jebelein and Kosti.

Uranotaenia balfouri Theobald.

Additional localities are Beika, Ezzo, Ghubeish area, Jebelein, Juba, Kawajena, Kosti, Nasir, L. Nyubor, Pibor mouth, Er Ruf, Shambe, Suki and Yambio.



Fig. 5.



Fig. 6.

Uranotaenia chorleyi Edwards.

Larvae have been found at Li Yubo (*P.H.A.*).

Uranotaenia annulata var. **apicotaeniata** Theobald.

Additional localities are Li Rangu (*W.R.*, adults in land-crab holes), Li Yubo, Loka, K. Nambire, Shittata, Wau (*N.N.*, bred from tin) and Yei (*W.R.*)

Uranotaenia candidipes Edwards.

A larva from Heiban (*A.A.B.*) appears to belong to this species.

***Uranotaenia ornata* var. *musarum* Edwards.**

The five available larvae, which have 10 to 13 comb-spines, are provisionally assigned to this variety because it occurs in Uganda. The Sudan localities are Li Rangu (*P.H.A.*, jar), Wau (*M.O.Z.*, banana plant) and Yambio (*A.T.*, cement basin).

***Uranotaenia mashonaensis* Theobald.**

The known localities are K. Aow, Bundle area, Kagelu, K. Kobwa, Libogo, Li Yubo, Maridi (*W.R.*), K. Nambire, Suni (larva) and Yei (*W.R.*).

***Uranotaenia fusca* Theobald.**

New records are from R. Eidi (larva), Kagelu (larva), K. Kobwa, Laboni, Myolo and Yei.

***Uranotaenia shillitonis* Edwards.**

The recorded locality, Katerunga, is believed to be in or very near the Sudan.

***Aëdomyia africana* Neveu-Lemaire.**

In the larva of this species and *A. fufurea* (End.) the sub-dorsal spines of the eighth abdominal segment have a peculiar shape, just visible in a chloral-gum mount, which has not previously been described. The bases of the spines are linear and parallel to each other and are orientated dorso-ventrally. Each spine consists of a shaft which curves upwards and bears a delicate dorsal blade which narrows from base to tip and bears numerous fine denticles along its edge.

Additional localities are Akobo and Jebelein. Larvae have been found in an artificial pool at Wad Medani but may have been introduced with water-plants from the White Nile.

***Aëdomyia fufurea* (Enderlein).**

In the only Sudan specimen seen, a larva from Sopo, the antennal papilla is as long as the distance from its base to the antennal tuft.



Fig. 7.

Fig. 8.

Theobaldia (Allotheobaldia) longiareolata (Macquart).

In specimens from Guldo and Kelling the mesonotal integument is dark. Several from Guldo and one from Wadi Halfa show Edwards' (1941) second type of variation.

Additional localities are Abka, Abungeda, Beika, Deriba (Abbott, 1948), Dongola, Ein Fara, El Fasher, Goled, Guldo, Gureir, Haro, Kebkabiya, Kelling, Kronga, Omdurman, Sawarda, So'unga, Summit, Umm Dom and Wadi Turo.

Larvae are numerous in natural pools on J. Marra and some have been found in a rock pool in the Nile at Abka, but in most of its range this species breeds largely in wells and perhaps can only survive, particularly in summer, where artificial containers are available.

Theobaldia (Theomyia) fraseri (Edwards).

In the three available specimens, larvae from Ezzo mounted and somewhat compressed in a gum-chloral medium, the siphon is brown and does not taper apically, and its tracheae are much wider distally than proximally. The saddle is brown and does not form a complete ring.

Ficalbia (Mimomyia) splendens (Theobald).

Additional localities are Bakht et Ruda, Bor, Dueim, Fangak, Nimule, Nzara, Tonga and Wad Medani (possibly introduced).

Ficalbia (Mimomyia) hispida (Theobald).

New records are from Adok, Danagla (adult), Bahr el Jebel km. 45 (adult), Jebelein, Lado (adult), Malakal (larva), Maridi, L. Nyubor, Tembura and Thar Jath.

F. (M.) hispida var. **palustris** (Theobald).

There are no new records.

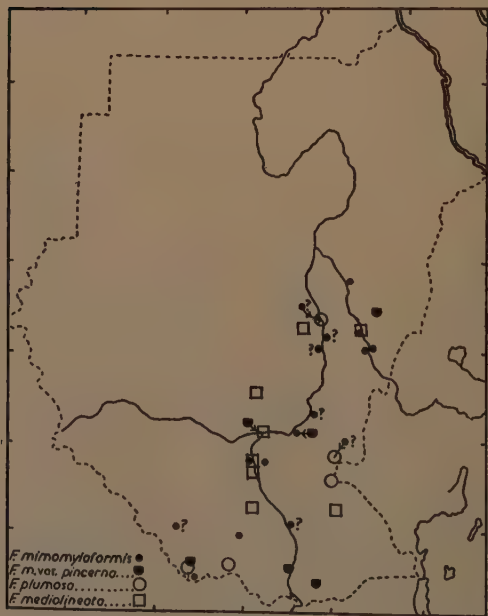


Fig. 9.



Fig. 10.

Ficalbia (Mimomyia) lacustris Edwards.

New records are from Jebelein, Kawajena, Li Rangu (adult), Nasir, L. No and L. Nyubor.

Ficalbia (Mimomyia) mimomyiaformis (Newstead).

In view of Hopkins' (1952) notes on the larvae, specimens with about 7 comb-spines (from 6 to 8 in nine larvae examined) are provisionally assigned to the type form and those with about 15 to var. *pincerna* (Graham).

Adults have been found at Abu Hugar, Danagla, Malakal, Siragia, Sueilik, Thar Jath, and a point on the Bahr el Zeraf; and larvae at Mvolo and Yambio. There are records of the type form, or possibly of the variety, from Bor, Jebelein, Keri Kera, Kosti (the variety ?), Mabu, Nasir (*J.F.E.B.*) and Panamtin.

F. (M.) mimomyiaformis var. *pincerna* (Graham).

In 23 larvae examined there are 12 to 17 comb-spines (average 14.6) in the anterior row, and 1 to 5 (average 2.7) in the posterior row. Larvae have been found at Hawata, Juba, Maingbara, Malakal, Torit and Wath Wang Kech.

Ficalbia (Mimomyia) plumosa (Theobald).

New records are from Akobo, Nasir area, Kosti and Nzara.

Ficalbia (Etorleptomyia) mediolineata (Theobald).

In a larva about to pupate, the large spine-like processes of the pupal paddles made the siphon appear to have internal teeth.

New records are from L. Nyubor and Wath Wang Kech.

Ficalbia (Ficalbia) uniformis (Theobald).

Edwards (1941) recorded this species from Lado.

Ficalbia (Ficalbia) malfeyti (Newstead).

Mattingly & Hamon (1955) have raised this form to specific rank and discussed its characters and distribution. It occurs at Abu Tong, Bahr el Jebel km. 182, Keri Kera, Kodok, Malakal, Shambe (Edwards, 1941), Thar Jath (Edwards, 1941) and Bahr el Zeraf km. 190. Larvae, probably of this species or *F. uniformis*, have been found at Ajwong, Buffalo Cape, Jebelein, Kosti, Talodi, Tonga and Zuleita.

Ficalbia (Ficalbia) circumtestacea (Theobald).

There are no new records apart from the finding of a larva of this species or *F. uniformis* at Li Yubo.

A larval character of some species of Ficalbia.

In the larva of most Sudan species of *Ficalbia*—*F. splendens*, *lacustris*, *hispida*, *mimomyiaformis*, *mimomyiaformis* var. *pincerna* and *uniformis*, as in the oriental *F. (Mimomyia) chamberlaini* (Ludlow) (Barraud, 1934), a very long fine hair arises from the inner surface of each posterior valve of the siphon. In *F. mimomyiaformis* var. *pincerna*, in which the hair is particularly well developed and about half as long as the siphon, it is thickened for a very short distance near its base, then bent sharply—outward when the valves are open and upward when they are closed—and near the tip is curved forward. When the valves are open these long hairs (of dead, and presumably of living larvae) lie along the surface of the water. It may be that they have a sensory function or assist in flotation or quick diving.

Taeniorhynchus (Coquillettidia) metallicus (Theobald).

New records are from Kodok, Taufikiya and Yambio.

Taeniorhynchus (Coquillettidia) pseudoconopas (Theobald).

Li Yubo is the only known locality in the Sudan.



Fig. 11.

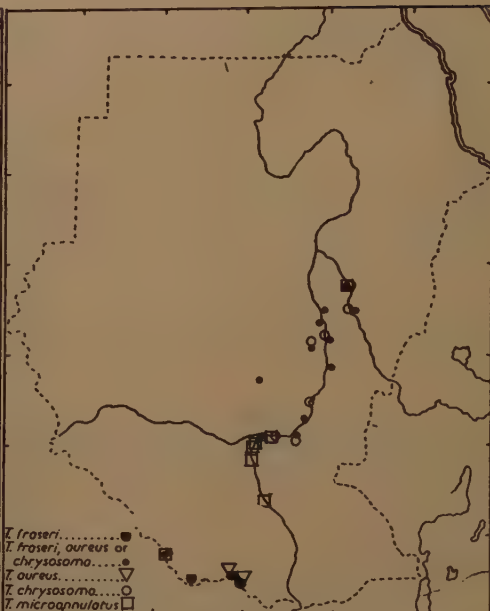


Fig. 12.

Taeniorhynchus (Coquillettidia) maculipennis (Theobald).

An additional locality is the Bundle area.

Taeniorhynchus (Coquillettidia) cristatus (Theobald).

An additional record is Bir Terab (Theobald, 1913).

Taeniorhynchus (Coquillettidia) fraseri (Theobald).

This species is known from Bundle area, K. Menzi and Yambio (C.E.W.).

Taeniorhynchus (Coquillettidia) chrysosoma Edwards.

Additional localities are Ghubeish area and 16 km. up the R. Sobat. This species, or possibly *T. fraseri*, occurs at Abd er Rasul, Barboi, Bundle, Kodok, Koma, Kosti, Malakal, Nambire, Renk, Er Ruat, Shawal, Wad Medani and Zuleita.

Taeniorhynchus (Coquillettidia) aureus Edwards.

There are no new records.

Taeniorhynchus (Coquillettidia) microannulatus (Theobald).

In view of Edwards' (1941) remarks about var. *auripennis* Edwards, all the Sudan records are here included in the type form. Most specimens examined are rather pale. Additional localities are Barboi, Buffalo Cape, Bahr el Jebel km. 80 and Li Yubo.

Taeniorhynchus (Mansonioides) africanus (Theobald).

The following are some of the many localities shown in fig. 14: Amadi, El Amira, Danagla, Hawata, Keilak, Lau, Li Rangu, El Liri, Li Yubo, Maingbara, Maridi, Nimule, Opari, Rahad and Talodi. The records of this species from El Fasher (Hewer, 1934) and of it and *T. uniformis* (Theo.) from El Fasher and Khandak (south of Dongola, 28.1.12) (Edwards, 1941) perhaps require confirmation.

Taeniorhynchus (Mansonioides) uniformis (Theobald).

Some of the localities are Amadi, El Amira, Danagla, Hashaba, Hawata, Jambo, Keilak, Khartoum, Lau, Li Rangu, Li Yubo, Maingbara, Maridi, Nimule (Coll. Brumpt, 30.ix.02, Neveu-Lemaire, 1906), Nyamlel, Opari, Rahad, Roseires, Er Ruat, Sennar, Shabak, Shukoli, Talha, Tertera, Torit, Umm Berembeita, Wad Medani and Yambio.



Fig. 13.

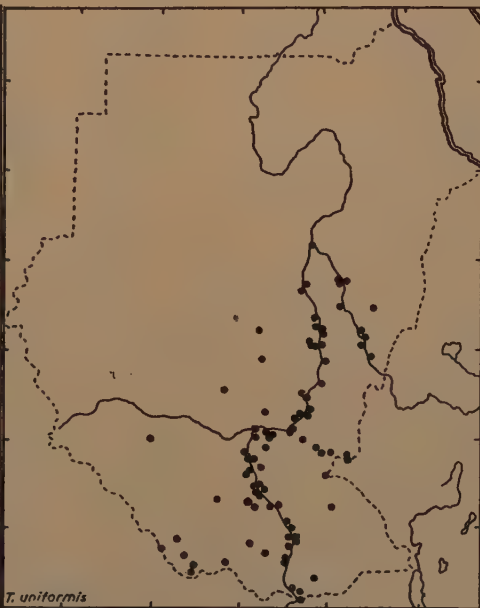


Fig. 14.

The genus Aedes.

Thirty three species and one variety occur in the Sudan (Lewis, 1955).

Eretmapodites chrysogaster Graham.

The examination of male terminalia shows that this species occurs at Li Rangu and Maridi. Females or larvae of this or a related species have been found at Li Yubo, Munderi, Mvolo and Yambio.

Eretmapodites intermedius Edwards.

Males have been found at Li Rangu, Maridi and Nzara.

Eretmapodites silvestris ssp. **conchobius** Edwards.

Hoogstraal & Knight (1951) studied Sudan specimens, noting differences from Edwards' description of Kenya specimens and describing the larva and pupa. They found many larvae in *Sansevieria* leaf axils around Torit, and reported that the adults were fierce biters.

Eretmapodites quinquevittatus Theobald.

Males have been examined from Juba and Wau (bred from larvae in snail shells). Females, probably of this species, have been found at Banga, and an indeterminable *Eretmapodites* at Opari.

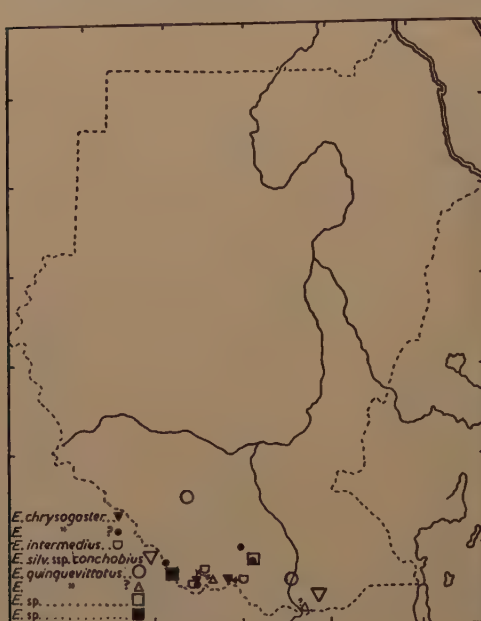


Fig. 15.



Fig. 16.

Eretmapodites sp.

A larva, possibly *E. dracaenae* Edw., has been found at Amadi.

Eretmapodites sp.

A larva from Ezzo (P.H.A.) may be *E. oedipodius* Graham.

The genus **Culex**.

Forty five species, two subspecies and one variety occur in the Sudan (Lewis, 1956b).

Many adults of *Culex* (102 males and 34 females comprising examples of *C. univittatus* Theo. and var. *neavei* Theo. and one of *C. duttoni* Theo.) were seen on the sepals of the shrub *Plumeria* sp., probably *P. acuminata*, at Ler after dark and before dawn. They were accompanied by 72 examples of *Anopheles funestus* Giles and 13 of *Taeniorhynchus uniformis*. Although the calyx of *P. acuminata* has no glands (Bailey, 1924) the calyx or some substances on it appeared to be more attractive than humans to the mosquitoes, as Philip (1943) once noted in America.

DISCUSSION ON FEATURES OF THE FAUNA.

One species of the DIXINAE, three species of CHAEBORINAE and 152 species, two subspecies and seven varieties of CULICINAE are known to occur in the Sudan and a few more may await discovery in the south.

Of the 45 species and two varieties of CULICINAE listed in the present paper, all except two are exclusively Ethiopian forms. Of the exceptions, *Theobaldia longiareolata* is a Mediterranean species which also extends into the Oriental

probably introduced from the south

Region, and fig. 16 shows approximately its distribution in the Sudan and three adjoining countries according to some of the authorities referred to by Lewis (1956a). *Taeniorhynchus uniformis* occurs also in the Oriental Region.

The distribution of several mosquitos in the Sudan and Egypt illustrates some aspects of the relation between the Ethiopian and Palaearctic faunas. Edwards (1941) points out that the mosquitos common to these two Regions outnumber those common to the Ethiopian and Oriental Regions, although the mosquito faunas of the two latter resemble each other more closely. Twenty three species (including those mentioned by Mattingly & Knight, 1956) are now known to occur in both the Ethiopian and Palaearctic Regions, namely, *Anopheles coustani* Lav., *A. culicifacies* Giles, *A. rhodesiensis* Theo., *A. dthali* Patt., *A. sergentii* (Theo.), *A. gambiae* Giles (recently exterminated in Egypt), *A. turkhudi* List., *A. multicolor* Camb., *A. pharoensis* Theo., *Theobaldia longiareolata*, *Aedes caballus* (Theo.), *Aë. caspius* (Pall.), *Aë. aegypti* (L.), *Aë. vittatus* (Big.), *Culex arbieeni* Salem, *C. poicilipes* (Theo.), *C. sitiens* Wied., *C. tritaeniorhynchus* Giles, *C. theileri* Theo., *C. univittatus* Theo., *C. sinaiticus* Kirkp., *C. laticinctus* Edw., *C. pipiens* L. and *C. antennatus* (Becker). A considerable proportion however (all the Anophelines and *Aë. caspius*, *C. arbieeni*, *C. poicilipes*, *C. sinaiticus* and *C. antennatus*), unlike most of the Ethiopian-Oriental species, do not penetrate far from one region to the other, or have a restricted distribution in the Ethiopian Region.

The interchange of species between the two Regions has been mainly from north to south, presumably because certain northern species could find suitable breeding places in the tropics in the form of cool permanent water in mountain streams and wells. Several of these species exist in the Red Sea Hills and further south. The two brackish-water species, *Anopheles multicolor* and *Aë. caspius*, have been able to extend a short distance into the Ethiopian lowlands, but *C. pusillus* only approaches the Ethiopian boundary.

In Africa, only six Ethiopian species (apart from the widespread *Aë. aegypti*) appear to have spread into the Palaearctic Region. These are *Anopheles rhodesiensis*, possibly along the Red Sea Hills, and *A. coustani*, *A. gambiae*, *A. pharoensis*, *C. poicilipes* and *C. antennatus* along the Nile. The five latter, which are common in the northern Sudan, probably spread north in the late Pleistocene or the Recent Geological Period. Ball (1939) suggested that the River Atbara was at that time enlarged by water from the then much bigger Blue and White Niles and from a large lake in the central Sudan. These species now breed chiefly in the rainy season, when the Nile is in flood and a warm damp southerly wind prevails, and one can easily imagine them breeding in former northern riverain swamps which may have resembled those that are formed along the Blue Nile at the present time. The populations of *A. coustani*, *A. pharoensis*, *C. poicilipes* and *C. antennatus* in Egypt now appear to be completely isolated from the Ethiopian Region.

Most species considered in this paper breed in swamps or wooded country, so scarcely any exhibit discontinuous distribution or "desert pallor" which are a feature of so many Sudan insects. *Dixa lunata*, however, occupies a remarkably isolated position. It is the only *Dixa* recorded during the 50 years in which CULICIDAE have been collected in the Sudan and it has doubtless existed in J. Marra for a long period. Pale specimens of *Chaoborus anomalus* are common at Khartoum.

Whitfield (1939) investigated the transport of mosquitos and other insects by aircraft in the Sudan and concluded that little was to be gained by further study. The present writer has, however, received for identification several mosquitos found in aircraft arriving at Khartoum, Geneina, Juba and Port Sudan between September 1938 and September 1954 inclusive, and the findings are summarised in the Annual Report of the Sudan Medical Service for 1954-55. The 53 specimens comprise: *Anopheles gambiae* (2), *A. pharoensis* (1), *A. squamosus* (1), *Anopheles*

sp. (1), *Theobaldia longiareolata* (2), *Taeniorhynchus fuscopennatus* Theo. (aircraft from Uganda) (1), *T. uniformis* (5), *Aedes* sp. (probably *caspius*) (1), *C. univittatus* (2), *C. sinaiticus* (1), *C. pipiens* or ssp. *fatigans* Wied. (17) and *Culex* sp. (19).

NOTES ON PRACTICAL IMPORTANCE.

Chaoborus anomalus forms a small proportion of the flies, chiefly CHIRONOMIDAE, which appear in vast numbers every winter at Khartoum and cause great annoyance. The presence of *Chaoborus* larvae, which are partly planktonic, indicates the lake-like nature of the Nile (in the dry season) in which the Chironomid larvae thrive.

Most of the man-biting mosquitos have been discussed in previous papers. Among the species of *Taeniorhynchus*, *T. africanus* and *T. uniformis* are particularly annoying and vast numbers bite man in the Sudd region. It has been suggested (see Lewis, 1947) that these species may play some part in the transmission of yellow fever which is widespread in the southern Sudan and broke out in the severe Nuba Hills epidemic of 1940. Hoogstraal & Knight (1951) wrote of *Eretmapodites silvestris conchobius* in the Sudan: "Because this mosquito, of potential importance in the transmission of yellow fever, is so common in an endemic yellow fever zone and so eagerly bites people tending their flocks or walking down the roadways or trails, it should be seriously considered in relation to yellow fever in Southeastern Anglo-Egyptian Sudan".

Summary.

One hundred and fifty six species, two subspecies and seven varieties of CULICIDAE are known to occur in the Sudan. The present paper shows the known distribution of members of the genera *Dixa*, *Chaoborus*, *Toxorhynchites*, *Harpagomyia*, *Hodgesia*, *Uranotaenia*, *Aëdomyia*, *Theobaldia*, *Ficalbia*, *Taeniorhynchus* and *Eretmapodites*, and includes taxonomic and other notes on several species.

Some aspects of distribution are discussed, particularly the exchange of species between the Ethiopian and Palaearctic Regions in which movement has been mainly from the latter to the former.

Brief notes are given on the practical importance of some species.

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References.

- ABBOTT, P. H. (1948). The Culicidae (Diptera) of Darfur Province. . .—Proc. R. ent. Soc. Lond., (B) 17, pp. 37–48.
- BAILEY, L. H. (1924). Manual of cultivated plants.—New York, Macmillan.
- BALL, J. (1939). Contributions to the geography of Egypt.—Cairo, Govt. Press.
- BARRAUD, P. J. (1934). The fauna of British India . . . Diptera. Vol. V. Family Culicidae. Tribes Megarhinini and Culicini.—463 pp. London, Taylor & Francis.
- EAST AFRICA HIGH COMMISSION (1952). East African Fisheries Research Organization. Annual report 1952.—Nairobi.

- EDWARDS, F. W. (1930). Notes on the exotic Chaoborinae, with descriptions of new species (Diptera, Culicidae).—Ann. Mag. nat. Hist., (10) **6**, pp. 528-540.
- EDWARDS, F. W. (1941). Mosquitoes of the Ethiopian Region. III. Culicine adults and pupae.—499 pp. London, Brit. Mus. (Nat. Hist.)
- FOOTE, R. H. (1953). Pictorial keys to the mosquitoes of medical importance. IV. Anglo-Egyptian Sudan.—Mosq. News, **13**, pp. 255-258.
- GILLET, J. D. (1949). Further notes on the Ethiopian species of *Taeniorhynchus* Arribalzaga (Diptera, Culicidae).—Proc. R. ent. Soc. Lond., (B) **18**, pp. 97-102.
- HEWER, T. F. (1934). Yellow fever in the Anglo-Egyptian Sudan. . .—Lancet, Sept. 1, pp. 496-499.
- HOOGSTRAAL, H. & KNIGHT, K. L. (1951). Observations on *Eretmapodites silvestris conchobius* Edwards (Culicidae) in the Anglo-Egyptian Sudan.—Amer. J. trop. Med., **31**, pp. 659-664.
- LEWIS, D. J. (1945). Observations on the distribution and taxonomy of Culicidae (Diptera) in the Sudan.—Trans. R. ent. Soc. Lond., **95**, pp. 1-24.
- LEWIS, D. J. (1947). General observations on mosquitos in relation to yellow fever in the Anglo-Egyptian Sudan.—Bull. ent. Res., **37**, pp. 543-566.
- LEWIS, D. J. (1955). The *Aedes* mosquitoes of the Sudan.—Ann. trop. Med. Parasit., **49**, pp. 164-173.
- LEWIS, D. J. (1956a). The Anopheline mosquitos of the Sudan.—Bull. ent. Res., **47**, pp. 475-494.
- LEWIS, D. J. (1956b). The *Culex* mosquitos of the Sudan.—Bull. ent. Res., **47**, pp. 703-721.
- LINDQUIST, A. W., ROTH, A. R. & WALKER, J. R. (1951). Control of the Clear Lake Gnat in California.—J. econ. Ent., **44**, pp. 572-577.
- MATTINGLY, P. F. (1954). East African Culicidae (Dipt.).—Arch. Hydrobiol., **48**, pp. 447-450.
- MATTINGLY, P. F. & HAMON, J. (1955). Position taxonomique et synonymie de quelques *Ficalbia* de la région Ethiopienne (Diptera, Culicidae).—Ann. Parasit. hum. comp., **30**, pp. 488-496.
- MATTINGLY, P. F. & KNIGHT, K. L. (1956). The mosquitoes of Arabia. I.—Bull. Brit. Mus. (nat. Hist.), Ent., **4**, pp. 91-141.
- NEVEU-LEMAIRE, M. (1906). Mission du Bourg de Bozas en Afrique tropicale. Etude des culicides africains.—Arch. Parasit., **10**, pp. 238-288.
- PHILIP, C. B. (1943). Flowers as a suggested source of mosquitoes during encephalitis studies, and incidental mosquito records in the Dakotas in 1941.—J. Parasit., **29**, pp. 328-329.
- VAN SOMEREN, E. C. C. (1949). Ethiopian Culicidae—*Eretmapodites* Theobald: description of four new species of the *chrysogaster* group with notes on the five known species of this group.—Proc. R. ent. Soc. Lond., (B) **18**, pp. 119-129.
- THEOBALD, F. V. (1913). New Culicidae from the Sudan.—Ann. trop. Med. Parasit., **7**, pp. 591-602.
- WHITFIELD, F. G. S. (1939). Air transport, insects and disease.—Bull. ent. Res., **30**, pp. 365-442.

STABILITY OF GRAIN AS A FACTOR INFLUENCING THE OVIPOSITION
RATE OF THE GRAIN WEEVIL, *CALANDRA GRANARIA* (L.)
(COL., CURCULIONIDAE).

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Calandra granaria (L.) is one of the major pests of stored grain in Great Britain, and forms part of the permanent insect population of grain residues in many granaries. The site of the residues may be deep within the fabric of the building (*e.g.*, wall cavities) or more superficial (*e.g.*, in cracks or lying loosely on floors or ledges). Should there be an appreciable delay between the removal of old grain and introduction of new, the number of insects attacking the new grain will depend, in part, upon the rate of oviposition in the residues.

Richards (1947) investigated many of the factors influencing the rate of oviposition of *C. granaria*, including the effect of different methods of presenting the grain. He found that the weevils laid more eggs on a small bulk of grain than they did when isolated with individual grains and that there was no significant difference in oviposition rate using 1, 2, 3, 4 and 5 grains. Richards suggested that "the critical number of grains is that number which builds up a stable bulk so that the weevil is not inconvenienced by grain movement."

In the unstocked granary, stable grains are found in wall cavities where there are large amounts of residue, or in such places as cracks in floors where individual grains are held by the sides of the cracks. If Richards' suggestion concerning the importance of stability is correct then there should also be an increase in the oviposition rate when grains are held in cracks. The following experiment was carried out to investigate this point and also to determine whether stability was the only operative factor when the grains were in cracks.

Method.

The insects used were obtained from laboratory stocks bred under the same conditions as those of the experiment (25°C., 65–70% R.H.). In order to reduce the variation found in oviposition rate among individuals a preliminary selection of females was made as follows. Adults of known age were sexed and 72 females transferred to individual tubes containing four grains of wheat which had been sterilised and conditioned. Oviposition over two 3-day periods was noted and, using total eggs laid and consistency over both periods as guides, 36 females were selected for the experiment.

Six methods of presentation of grain were used, each of which was replicated three times. Thirty grains of wheat were used in each replicate.

(1) Grain in cracks in wood. Two parallel cracks were cut in a block of wood which was sealed with plaster of Paris into the base of a plastic container (8.5 × 8.5 cm. cross-section and 8 cm. high). The cracks were 4 mm. across, 5 mm. deep and 4 cm. apart.

(2) Grain in cracks in plaster of Paris. The base of a 10 cm. petri dish was covered with plaster of Paris into which two parallel cracks were cut. The cracks were 3 mm. across, 5 mm. deep and between 3.5 and 4 cm. apart.

(3) Grain gummed to glass; in rows. Two parallel rows of grains, 4 cm. apart, were gummed to the base of a 10 cm. petri dish using gum tragacanth.

(4) Grain gummed to glass; scattered. Grains were gummed to a 10 cm. petri dish to give a general coverage of the base. The average distance between grains was 1 cm.

(5) Grain loose on glass. The grains were scattered over the base of a 10 cm. petri dish.

(6) Grain loose on plaster of Paris. The base of a 10 cm. petri dish was covered with plaster of Paris and grain was scattered over this surface.

Two of the selected females and one male were introduced into each dish and kept at 25°C. and 65–70 per cent. R.H. for eight days when the number of eggs was counted and the grain renewed. (A duplicate set of dishes was made for the gummed-grain treatments, so that after gumming it was possible to leave the grains for five days in experimental conditions to re-equilibrate.) The experiment was continued for four periods of eight days. It was intended to transfer insects from one condition to another after the fourth period and this was carried out, but the mortality rate of the females was so great that no valid results were obtained. Previously, only three females had died and these had been replaced by tested females with a similar egg production.

The eggs were counted by dissecting the grains after they had been stained with acid fuchsin (Frankenfeld, 1948). The egg plugs, which take up the stain, were used as guides to the presence of eggs but only those eggs actually revealed by dissection were counted.

The Effect of Method of Presentation of Grain upon Oviposition Rate.

As will be seen from Table I, the only significant differences found were between fixed- and loose-grain treatments. There was no significant difference between fixed grain in cracks and in rows, nor between fixed grain in rows and scattered.

TABLE I.

The effect of method of presentation of grain upon oviposition.

Age (days)	Fixed				Loose		Total
	Cracks		Gummed		Plaster	Glass	
	Plaster	Wood	Rows	Scattered			
18—25	54 50 63	59 58 61	69 56 61	69 57 63	58 55 51	53 60 44	1041
26—33	55 59 69	65 60 65	62 57 54	76 50 64	58 47 55	54 58 48	1056
34—41	54 55 59	58 51 63	63 52 —	62 50 64	54 39 42	52 48 36	902
42—49	51 48 47	50 36 56	42 43 51	49 — 52	35 38 26	41 43 —	708
Total	664	682	610	656	558	537	3707
Mean	55.3	56.8	55.4	58.8	46.5	48.0	

Three pairs of females were used for each treatment.

Among the mean values, 48.0 differs significantly from 55.3 at $P = .05$; but those within the range 55.3–58.8 or 46.5–48.0 do not differ significantly.

Therefore, the increase in oviposition found when grains are placed in cracks must be due to the fixing of the grains and not to the fact that the grains are partially enclosed or arranged in rows. The nature of the material surrounding

the crack had no effect. Comparison of the two treatments of loose grain shows that the slightly rougher surface of plaster of Paris did not increase the rate of oviposition above that on glass.

The analysis of variance revealed a significant effect of age on the egg output, but no differential effect of age upon oviposition under the various treatments was found. The increase in oviposition due to grain being fixed was not, therefore, counteracted by a more marked falling off in this treatment later in the experiment.

The Effect of Cracks upon the Distribution of Eggs among the Grains.

C. granaria usually lays at random in uninfested wheat (Richards, 1947). The fact that grains are in cracks and some probably less accessible than others might be thought to reduce the number available for oviposition and alter the distribution of eggs so that it is no longer random. This would have the effect of increasing the degree of superinfestation. Analysis of experimental results shows that the distribution of eggs is not significantly different from random (Table II) and that

Table II.

The distribution of eggs in grains compared with random distribution (Poisson series).

Eggs/grain	Cracks		Gummed		Loose	
	(a)	(b)	(a)	(b)	(a)	(b)
0	63	48.9	52	46.8	56	60.7
1	86	97.7	85	95.6	112	108.0
2	89	97.4	103	97.7	98	96.2
3	66	64.8	66	66.5	54	57.0
4	36	32.3	35	34.0	34	25.4
5	12	12.9	14	13.9	3	} 12.4
6+	8	5.9	6	6.5	3	
Mean	1.99		2.04		1.78	
χ^2	7.403		2.117		8.680	
(c)	11.07		11.07		9.488	

(a), numbers observed; (b), numbers expected;
(c), value of χ^2 required for significance at $P = .05$.

the increase in superinfestation when grains are in cracks is only that to be expected from an increase in the mean number of eggs per grain. The greatest discrepancy between observed and expected results occurs in the comparison of the numbers of uninfested grains when the latter are in cracks. There is some indication, therefore, that when grains are in cracks the effective number available might be slightly reduced, but this effect is not sufficiently marked to cause a significant variation from random distribution of eggs in grains.

The development of *C. granaria* takes place within the grain in which the egg is deposited and it is only very rarely that more than one adult emerges from any grain. Increase in oviposition leading only to superinfestation has, therefore, little effect upon the rate of increase of the population. The effectiveness of any increase in oviposition depends on the additional number of grains infested and

this (when eggs are distributed at random) varies according to the mean number of eggs per grain.

For a constant increase in oviposition, the Poisson series that represent the distribution of eggs will show a relatively large increase in the numbers of grains infested up to a mean concentration of about two eggs per grain, less between two and five and above this hardly any. The effectiveness of the increased oviposition due to grains being fixed will, therefore, vary according to the density of the *Calandra* population, being greatest when density is low and minimal when density is high.

Discussion.

The experiments substantiate the claim by Richards (1947) that the reduction in oviposition rate of *C. granaria* on a small number of grains is, at least in part, due to the instability of the grains. Stability can be attained either by using a large bulk (Richards, 1947) or by fixing the grains in cracks. In granary residues both of these conditions may be found.

On the floors of unstocked granaries the grains may lie loosely or in cracks. The effect of the cracks will be to increase the chances of an appreciable infestation building up in these superficial residues by increasing the stability of grains and thus increasing the number of eggs laid. Also, because the number of grains remaining after removal of stocks is likely to be greater when cracks are present, the proportion of the increased egg output wasted upon superinfestation will be reduced.

In the experiment, only two types of uninterrupted floor were used and both of these were relatively smooth. It is quite probable that a very rough cement floor would provide grains with sufficient stability to increase the oviposition rate of *C. granaria* over that attained on a smooth floor.

Summary.

In order to estimate the effect of cracks in floors upon the oviposition rate of *Calandra granaria* (L.) in an unstocked granary, grain was presented to adults in six ways. The grain was either fixed or loose. Fixation was achieved either by placing grain in cracks in wood or plaster of Paris, or by gumming (in rows or scattered) to glass. The loose grains lay upon glass or plaster of Paris.

A significantly greater number of eggs was laid upon grain that was fixed. The fact that the grains were in rows and partially enclosed when in cracks had no greater effect than fixing with gum. There was no significant departure from a random distribution of eggs in grains when the latter were in cracks.

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References.

- FRANKENFELD, J. C. (1948). Staining methods for detecting weevil infestation in grain.—U.S. Dep. Agric. Bur. Ent., ET-256, 4 pp. multigraph.
- RICHARDS, O. W. (1947). Observations on grain-weevils, *Calandra* (Col., Curculionidae). I. General biology and oviposition.—Proc. zool. Soc., **117**, pp. 1-43.
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THE RICE ROOT APHID.

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For several years entomologists in many parts of the world have been aware of an Aphid which attacks the roots of rice and other Gramineae. This Aphid is closely related to the Bird-cherry Aphid, *Rhopalosiphum padi* (L.), and the Oat-Apple Aphid, *Rhopalosiphum insertum* (Walker) (syn. *R. crataegellum* Theobald), with either or both of which it has sometimes been confused. Rogerson (1947), in a paper dealing with the morphological and biological differences between *R. padi* and *R. insertum*, pointed out that certain earlier authors in Britain and America had failed to distinguish between these species and had included both under the name *R. prunifoliae* (Fitch). Previously Börner & Schilder (1932, p. 594) had shown that *Aphis avenae* Fabricius of Theobald was in fact *Rhopalosiphum padi* (L.), and it appears that various other authors in America and Japan had confused these two species. An examination of the literature shows that the Rice Root Aphid also was partly involved in the same confusion of nomenclature.

Some workers, however, realising that the Rice Root Aphid is a distinct species, have described and figured it under several different names in a variety of publications. It is the present writer's intention to attempt to establish its correct systematic position.

Distinguishing Characters and Systematic Position.

Enough descriptions of the Rice Root Aphid already exist to make it unnecessary to redescribe it fully here.* It will be sufficient to remark that it differs from other species of *Rhopalosiphum* in having long, fine hairs on the body and antennae, those on the latter being about equal to the diameter of the third antennal joint in the alatae, and up to twice or more the diameter of the same joint in the apterous forms. Eastop (1954) notes also that it has from four to six hairs on the eighth abdominal tergite, instead of the two normally present in other members of the genus. In common with *R. insertum* it has a *processus terminalis* from four-and-a-half to six times as long as the base of the terminal antennal joint. In all major respects it accords closely with the modern conception of *Rhopalosiphum* Koch, including the possession of small lateral papillae on the prothorax and abdominal segments 1 and 7, and a reticular pattern of minute blunt spinules on the dorsal abdominal cuticle. Like other species of this genus the Rice Root Aphid has a tendency to produce both apterous and alate exules in which the number of antennal joints is reduced to five. This has led certain workers, who have encountered only the forms with five-jointed antennae, to place it in genera in which this condition is characteristic, e.g., *Cerosipha* del Guercio, *Yamataphis* Matsumura, and *Aresha* Mordvilko. (As the last two of these genera were erected with the Rice Root Aphid as type, they must sink as synonyms of *Rhopalosiphum*.) Furthermore, the fact that in species of *Rhopalosiphum* the second fork of the media normally lies very close to the wing margin, and in some specimens may be absent altogether, accounts for the Rice Root Aphid having been assigned to *Toxoptera* Koch, the type species of which has the media only once branched.

* Excellent descriptions, with figures, are given by Cottier (1953, pp. 159-162) and Willcocks (1925, pp. 115-118).

Accounts of the colour of the living Rice Root Aphid vary considerably, but most authors agree that the abdomen in the apterous female is dark green or brownish, often with a reddish area at the hind end between and around the siphunculi.

Below is given what is believed to be a reasonably complete synonymy* of the Rice Root Aphid, followed by a brief summary of the published records relating to it.

Rhopalosiphum rufiabdominalis (Sasaki).

Toxoptera rufiabdominalis, Sasaki, 1899, p. 202

12.9 *Siphocoryne splendens*, Theobald, 1915, pp. 116-118

15 *Yamataphis oryzae*, Matsumura, 1917, pp. 412-414

11 *Aresha shelkovnikovi*, Mordvilko, 1921, p. 54

Yamataphis papaveris, Takahashi, 1921, p. 39

Yamataphis rufiabdominalis, Takahashi, 1921, p. 43

Rhopalosiphum avenae partim, Takahashi, 1923, pp. 34-35

14.13.9 *Rhopalosiphum avenae*, George, 1925, pp. 309-310

Aphis splendens, Hall, 1926, p. 26

10 *Rhopalosiphum prunifoliae* partim, Theobald, 1927, p. 72

Rhopalosiphum annuae partim, Börner & Schilder, 1932, p. 594

28.34.38 *Rhopalosiphum subterraneum*, Mason, 1937

Aresha setigera, Blanchard, 1939, pp. 900-902

27.28 *Rhopalosiphum splendens*, Palmer, 1939

10 *? Pseudocerosipha pruni*, Shinji, 1941, p. 1011

34 *Cerosipha californica*, Essig, 1944, pp. 117-119

10 *Cerosipha subterranea*, Zimmerman, 1948, pp. 93-94

Host-plants.

GRAMINEAE: *Arundo* sp., *Avena algeriensis*, *Avena* sp., *Bromus* sp., *Cynodon dactylon*, *Cyperus* sp., *Eleusine coracana*, *Eleusine indica*, *Hordeum polystichum*, *Hordeum sativum*, *Hordeum vulgare*, *Hordeum* sp., *Lolium perenne*, *Lolium rigidum*, *Lolium* sp., *Oryza montana*, *Oryza sativa*, *Panicum colonum*, *Saccharum officinale*, *Triticum dicoccoides*, *Triticum durum*, *Triticum sativum*, *Triticum vulgare*, *Triticum* sp.

OTHER PLANTS: *Papaver somniferum*, *Gossypium* sp., *Hibiscus esculentus*, *Phaseolus vulgaris*, *Prunus cerasifera*, *Prunus mume* (?), *Prunus persica* (?), *Prunus serotina* (?), *Prunus* sp., *Oenothera laciniata*, *Apium graveolens*, *Solanum lycopersicum*, *Solanum tuberosum*, *Solanum* sp., *Orobancha* sp., *Gnaphalium* sp., *Parthenium argentatum*, *Iris* sp., *Psilopilum crispulum*.

Distribution.

The Rice Root Aphid has been recorded from the following localities:—Argentina, Dutch Guiana, Egypt, Fiji, Formosa, Hawaii, South India, Israel, Japan, Kenya, Morocco, New Zealand, Peru, Spain, Tanganyika, Tristan da Cunha, United States of America.

The Rice Root Aphid in eastern Asia.

The earliest account of the Rice Root Aphid appears to be that of Sasaki (1899), who described and figured what he called the "Upland-Rice Pink Aphis", from the roots of rice in the Tokyo Prefecture, and to which he gave the name *Toxoptera rufiabdominalis*, sp.n. His figures, though somewhat crudely drawn,

* The full details of the papers referred to in the synonymy will be found in the list of references on p. 747.

show clearly an apterous female (or larva) with long hairs on body and antenna, an antenna of five joints with the *processus terminalis* at least five times as long as the base of the fifth, and a large shaded area on the hind abdomen around the bases of the siphunculi. He states that "the trunk is light yellowish green or blue . . . and the rear half of the abdomen is reddish brown". He figures also an alate female with five-jointed antenna similar to that of the aptera, and a forewing with the media once branched. He says "the head and thorax are dark grey-brown, while the abdomen is orange-red coloured. . . . The grey antennae consist of six joints,* the first, second, fourth and fifth being small and short, while the third is thin and long and the sixth extremely thin and long and whip-shaped".

Eighteen years later Matsumura (1917) rediscovered the Rice Root Aphid attacking the roots of rice in Hokkaido and described it as new, erecting for it the genus *Yamataphis*, characterised by five-jointed antennae, with, as type, *Yamataphis oryzae*, sp.n. He described the body of the alate female as "fuscous, with a purple shade, abdomen somewhat paler", and gave the length of the *processus terminalis* as nine times that of the base of the terminal joint; his figure, however, does not support this, showing a *processus* only about six times as long as the base. He realised that this Aphid was closely allied to *rufiabdominalis* Sasaki, which he also placed in *Yamataphis*, but believed it to differ from it in size and colour. There seems no reason to doubt that the two are identical.

Takahashi (1921) records the Rice Root Aphid—as *Yamataphis rufiabdominalis* (Sasaki)—as of doubtful occurrence in Formosa, and in the same Report describes *Yamataphis papaveris*, sp.n. from the roots of *Papaver somniferum* in Formosa. His description and figures of the latter agree in all important respects with *rufiabdominalis*. In a later instalment of the same Report Takahashi (1923) revises his opinions and includes *rufiabdominalis* Sasaki, *oryzae* Matsumura, and *papaveris* Takahashi along with—among others—*padi* Kaltenbach, *annuae* Oestlund, *maidis* Essig, and *prunifoliae* Baker, as synonyms of *Rhopalosiphum avenae* (Fabricius) (i.e., *padi* Linnaeus). He adds that, in his opinion, *Aresha shelkovnikovi* Mordvilko 1921 seems also to be a synonym of *R. avenae* (F.). Unfortunately he gives no description of his *avenae*, but it may be noted that he records as its hosts in Formosa only *Prunus mume*, *Papaver somniferum* and *Oryza sativa*, which suggests at least the possibility that he was dealing with the Rice Root Aphid alone, rather than a mixture of that and *R. padi* as the synonymy implies. There is evidence that the Rice Root Aphid uses *Prunus* as its primary host.

George (1925) uses a synonymy almost identical with that of Takahashi (but omitting *maidis* Essig) in his account of *Rhopalosiphum avenae* (F.) in South India, but his description and figures make it plain that in fact he is dealing only with *R. rufiabdominalis* (Sasaki). He gives the colour of the aptera as dark green with two light red areas near the siphunculi, and states that the alate form is darker. He records it from the roots of *Eleusine coracana* and *Panicum colonum*.

Hori (1926), who deals at some length with *Rhopalosiphum avenae* (F.) in Japan, gives a synonymy again very similar to those of Takahashi (1923) and George (1925), but in this case it is clear that he is concerned with a mixture of at least three species of which the Rice Root Aphid is one. In a coloured plate he shows, all under the name *Rhopalosiphum avenae* (F.), what appear to be an alate female of *R. padi* (L.) (fig. 3), an apterous female of *R. insertum* (Walker) (fig. 1), and an apterous female of *R. rufiabdominalis* (Sasaki) (fig. 4). His list of host-plants, moreover, includes not only *Prunus* spp. (the primary

* i.e., counting the *processus terminalis* and the base of the fifth as separate joints, making six in all.

hosts of *R. padi* and *R. rufiabdominalis*), but *Crataegus*, *Cydonia*, and *Malus* spp. (the primary hosts of *insertum*), as well as a variety of Gramineae, including *Oryza sativa*.

In a later paper, Hori (1929, pp. 124–129) again describes the same mixture of species, but this time under the name *Rhopalosiphum prunifoliae* (Fitch), a name also used later in the same sense by Takahashi (1931, p. 51), Wu (1935) and Shinji (1941, p. 665). Shinji, in the same work (1941, p. 1011), lists also a new genus and species of his own, *Pseudocerosipha pruni*, which, to judge by his figures, is certainly a *Rhopalosiphum* and could be *rufiabdominalis*. Both apterous and alate forms are shown with five-jointed antennae, but the hairs on the antenna of the aptera are rather shorter than is typical for the Rice Root Aphid. If this supposition is correct, Shinji would be describing here the forms on the primary hosts, which he gives as *Prunus* spp. including *P. serotina*, *P. mume*, and *P. persica*.

The Rice Root Aphid in Africa.

In 1908, Willcocks found what has since been identified as the Rice Root Aphid attacking the roots of wheat in Egypt. His material was described by Theobald (1915), who named it *Siphocoryne splendens*, sp.n.* and recorded that the abdomen of the apterous female was "dull olivaceous green or obscure orange" and the "area between and surrounding base of cornicles crimson". Willcocks (1925, pp. 115–118), using the same name, gives a somewhat fuller description than Theobald's, supported by excellent coloured illustrations, and notes the occurrence of individuals with five- and six-jointed antennae. His list of host-plants is fuller, and includes *Oryza sativa*. Hall (1926, p. 26), who also records *splendens* from Egypt, places it in the genus *Aphis*, as does Mimeur (1934, p. 33), who found it on the roots of *Oryza montana* and various other Gramineae in Morocco. The latest record of the Rice Root Aphid in Africa is that of Eastop (1954), who found it in the Kenya Highlands and the Southern Province of Tanganyika.

The Rice Root Aphid in America and elsewhere.

In a paper entitled "A New Root Aphid", Mason (1937) describes *Rhopalosiphum subterraneum*, sp.n., an Aphid found on cotton roots in South Carolina, and states that specimens taken on other hosts and in other localities have been in the United States National Collection since 1900. Although he describes both the apterous and alate females as brown in colour and makes no mention of red coloration around the siphunculi, morphologically they correspond closely with *R. rufiabdominalis* (Sasaki). The Aphid is recorded from most of the eastern States of the U.S.A. and from California, feeding on the roots not only of Gramineae but on dicotyledons of various kinds also.

Palmer (1939) records the Rice Root Aphid—as *Rhopalosiphum splendens* (Theobald)—from the roots of wheat in Nebraska and Colorado, and distinguishes it from *R. prunifoliae* (Fitch) by its colour and the length of the hairs on body and antennae. In her book "Aphids of the Rocky Mountain Region" Palmer (1952, pp. 223–224) regards *subterraneum* Mason as doubtfully distinct from *splendens* Theobald on account of its colour in life. It seems hardly justifiable to regard a single, very variable character as a valid distinction between species which are morphologically and biologically so similar.

The Rice Root Aphid appears again as *Cerosipha californica* Essig, found on the roots of *Parthenium argentatum*, *Solanum tuberosum*, and on *Prunus* leaves, in California (Essig, 1944).

In South America the Rice Root Aphid is recorded by Essig (1953, pp. 77–78)—as *Rhopalosiphum splendens* (Theobald)—from the roots of grasses in Peru,

* Types in the British Museum (Natural History).

and by Hille Ris Lambers (1955) from Dutch Guiana (and also from Tristan da Cunha). Blanchard (1939, pp. 900-902) describes what appears to be the same species from rice roots in Argentina under the name *Aresha setigera*, sp.n. The genus *Aresha* was erected in 1921 by Mordvilko in his "Keys for the Determination of Aphids living continuously or temporarily on Gramineaceous Plants and Sedges".* It contained the single species *Aresha shelkovnikovi* Mordvilko, recorded from the roots of rice in the South Russian province of Elisavetpol (Azerbaijan). Although his description is very brief and without figures, it contains nothing which conflicts with the assumption that Mordvilko, too, is describing the Rice Root Aphid. Blanchard claims that his *setigera* differs from *shelkovnikovi* only in having longer antennal hairs, the longest of which (according to his figure of the aptera) are rather more than twice the diameter of the third antennal joint, whereas Mordvilko describes the corresponding hairs of *shelkovnikovi* as being "almost twice" the diameter of the joint. In all other respects the morphological characters, so far as they are described, agree closely, and as both species were recorded only from the roots of rice, it seems reasonable to assume that both may well be synonymous with *Rhopalosiphum rufiabdominalis* (Sasaki). It should be added that, at the time he erected the genus *Aresha*, Mordvilko was aware of the existence of *splendens* Theobald and its probable relationship with *padi* L. In a footnote (Mordvilko, 1921, translation, p. 30) he points out that *splendens* has longer hairs on the antennae and larger siphunculi than *padi*, but, perhaps because *splendens* was recorded only from the roots of wheat, he fails to connect it with *shelkovnikovi*, which was found on rice.

Cottier (1953, pp. 159-162), who records the Rice Root Aphid in New Zealand, mentions Takahashi's belief, referred to above, that *Aresha shelkovnikovi* is a synonym of *Rhopalosiphum avenae* (F.) (i.e., *padi* L.). But Cottier mentions further that Takahashi subsequently admitted (*in litt.*) that he had confused *avenae* F. and *splendens* Theobald in his description of the former, and added that *Aresha shelkovnikovi* Mordv., *Rhopalosiphum papaveris* (Tak.), *R. subterraneum* Mason and *Yamataphis oryzae* Mats. may be synonyms of *Rhopalosiphum splendens* (Theobald). It appears that Takahashi was the first to realise that the Far Eastern species of the Rice Root Aphid were identical with those of Africa and America. It is strange, however, that he failed to recognise *rufiabdominalis* Sasaki as the earliest valid name, despite the fact that he regarded it as a good species in 1921.

It remains only to add that the Rice Root Aphid has been found in the Pacific Islands of Hawaii (Zimmerman, 1948, pp. 93-94) and Fiji (specimens in British Museum (Natural History) collections). A single alata taken on *Psoralea* from Carreira Island, Spain (also in the B.M. (N.H.) collections), forms the only record to date from western Europe. = *madeira*

Hallaphis, gen. nov.

Among his descriptions of new aphid species from Southern Rhodesia, Hall (1932) includes an Aphid, similar in some respects to the Rice Root Aphid, which he named *Yamataphis rhodesiensis*, sp.n. As has been stated, the genus *Yamataphis* Matsumura must now be regarded as a synonym of *Rhopalosiphum* Koch, but as *rhodesiensis* Hall differs in too many respects to allow it to be included in that genus, a new genus must be erected for it. The name *Hallaphis* is proposed, with the following diagnosis:

Body rather small, broad and compact. Cuticle of head, thorax, abdomen and proximal parts of appendages minutely spinulose, densely so in apterae. Body hairs acute, rather stout, of medium length, longer on head and tergites

* An English translation of Mordvilko's paper was published in Bull. ent. Res., 13, pp. 25-39, 1922.

7 and 8. Antennae of five joints (in all specimens so far seen), less than half body length, secondary rhinaria* with thick rims, confined to third joint, base of fifth joint short and thick. Frontal margin almost flat, without prominences. Rostrum reaching past third coxae, ultimate joint long and rather narrow (about twice length of hind tarsus 2 in type species). Lateral abdominal tubercles absent. Siphunculi rather short and thick, densely and finely spinulose, deeply constricted before the widely flared flange. Cauda small, short and U-shaped, with 4 or 5 hairs. Forewing normally with media twice branched, the distance of the second branch from the wing margin very variable, from normal aphidine to absent altogether. Hind wing with only one oblique vein.

The main differences between *Hallaphis rhodesiensis* (Hall) and *Rhopalosiphum rufiabdominalis* (Sasaki) may be tabulated as follows:—

<i>H. rhodesiensis</i> .	<i>R. rufiabdominalis</i> .
Head spinulose.	Head smooth.
Proc. term. \pm 3 times base of V.	Proc. term. $4\frac{1}{2}$ –6 times base of V.
Ult. rostral joint \pm twice hind tarsus 2.	Ult. rostral joint less than $1\frac{1}{2}$ times hind tarsus 2.
Lateral abdominal tubercles absent.	Lateral abdominal tubercles present on prothorax and abd. segments 1 and 7.
Antennal hairs numerous.	Antennal hairs sparse.
Longest hairs on antennal joint 3 in apterae about equal to diameter of joint.	Longest hairs on antennal joint 3 equal to about twice joint diameter.
Cauda short, inconspicuous, U-shaped.	Cauda more or less conical, or with broad base narrowing to middle, distal half finger-shaped.
Hind wing with one oblique vein.	Hind wing with two oblique veins.

Types of *Hallaphis rhodesiensis* (Hall) in the British Museum (Natural History).

Summary.

Independent discoveries of an Aphid attacking the roots of rice and other Gramineae in different parts of the world have led to its description under different names, and its affinity with other species has sometimes resulted in its confusion with them. The literature relating to the species is reviewed and it is shown that the correct name for it is *Rhopalosiphum rufiabdominalis* (Sasaki), of which *Prunus* is the primary host.

What is believed to be a reasonably complete synonymy is given and this involves the sinking of the two genera *Yamataphis* Matsumura and *Arescha* Mordvilko as synonyms of *Rhopalosiphum* Koch because both of these genera were erected with the Rice Root Aphid as type. A species that was described as *Yamataphis rhodesiensis* Hall differs in too many respects to permit its inclusion in *Rhopalosiphum* and a new genus, *Hallaphis*, is erected for its reception.

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* Hall records that rhinaria occur on the third antennal joint in the apterae as well as in the alatae. His original sample contains some alatiform apterae which suggests that the presence of rhinaria in the aptera may be abnormal. In a sample collected recently by Mr. V. F. Eastop the apterae were without secondary rhinaria.

References.

- BLANCHARD, E. E. (1939). *Physis*, **17**, pp. 857-1003.
- BÖRNER, C. & SCHILDER, F. A. (1932). In Sorauer, *Handb. Pflanzenkr.*, **5**, II. Teil, pp. 551-715.
- COTTIER, W. (1953). *Bull. N. Z. Dep. sci. industr. Res.*, no. 106, 382 pp.
- EASTOP, V. F. (1954). *E. Afr. agric. J.*, **20**, pp. 129-132.
- EASTOP, V. F. (1955). *E. Afr. agric. J.*, **20**, pp. 209-212.
- ESSIG, E. O. (1944). *Hilgardia*, **16**, pp. 177-184.
- ESSIG, E. O. (1953). *Proc. Calif. Acad. Sci.*, (4) **28**, pp. 59-164.
- GEORGE, C. J. (1925). *J. Asiat. Soc. Beng.*, (N.S.) **20**, pp. 307-311.
- HALL, W. J. (1926). *Bull. Minist. Agric. Egypt*, no. 68, 62 pp.
- HALL, W. J. (1932). *Stylops*, **1**, pp. 49-61.
- HARPAZ, I. (1953). Ecology, phenology and taxonomy of the Aphids living on graminaceous plants in Israel. [*In Hebrew with English summary.*]-15 pp. Jerusalem, Hebrew Univ.
- HILLE RIS LAMBERS, D. (1948). *Trans. R. ent. Soc. Lond.*, **99**, pp. 269-289.
- HILLE RIS LAMBERS, D. (1955). Results of the Norwegian Scientific Expedition to Tristan da Cunha 1937-38, no. 34.
- HORI, M. (1926). *Rep. Hokkaido agric. Exp. Sta.*, no. 17, pp. 1-49.
- HORI, M. (1929). *Rep. Hokkaido agric. Exp. Sta.*, no. 23, 163 pp.
- MASON, P. W. (1937). *Proc. ent. Soc. Wash.*, **39**, pp. 166-167.
- MATSUMURA, S. (1917). *J. Coll. Agric.*, Sapporo, **7**, pp. 351-414.
- MIMEUR, J. M. (1934). *Mem. Soc. Sci. nat. Maroc*, no. 40, 71 pp.
- MINOBE, S. & FUJII, K. (1903). *Spec. Rep. Aichi prefect. agric. Exp. Sta.*, no. 1.
- MORDVILKO, A. K. (1921). *Bull. Sta. rég. Prot. Plantes Petrograd*, **3**, pp. 1-72.
- PALMER, M. A. (1939). *J. econ. Ent.*, **32**, pp. 345-346.
- PALMER, M. A. (1952). Aphids of the Rocky Mountain Region.—Thomas Say Foundation, **5**, 452 pp.
- ROGERSON, J. P. (1947). *Bull. ent. Res.*, **38**, pp. 157-176.
- SASAKI, C. (1899). *Nippon nosakumotsu gaichu hen.* (Manual of crop insect pests in Japan), p. 202.
- SHINJI, G. O. (1941). *Monograph of Japanese Aphids.*—1215 pp. Tokyo.
- TAKAHASHI, R. (1921). *Aphididae of Formosa. Part I.*—97 pp. Taihoku, Agric. Exp. Sta. Formosa.
- TAKAHASHI, R. (1923). *Rep. Dep. Agric. Govt Res. Inst. Formosa*, no. 4, 173 pp.
- TAKAHASHI, R. (1931). *Rep. Dep. Agric. Govt Res. Inst. Formosa*, no. 53, 127 pp.
- THEOBALD, F. V. (1915). *Bull. ent. Res.*, **6**, pp. 103-153.
- THEOBALD, F. V. (1927). *The plant lice or Aphididae of Great Britain. Vol. II.*—411 pp. London, Headley.
- WILLCOCKS, F. C. (1925). *The insect and related pests of Egypt. Vol. II.*—418 pp. Cairo, Sultanic Agric. Soc.
- WU, C. F. (1935). *Catalogus insectorum sinensium*, **2**, p. 148.
- ZIMMERMAN, E. C. (1948). *Insects of Hawaii. Volume 5. Homoptera: Sternorrhyncha.*—464 pp. Honolulu, Univ. Hawaii Pr.

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RESPONSES OF PESTS TO FUMIGATION.

VI.—WATER LOSSES AND THE MORTALITY OF *CALANDRA* SPP. AT REDUCED PRESSURES.*

By H. J. BHAMBHANI

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In Part IV of this series, El Nahal (1953) reviewed the evidence which shows that the amount of water lost by insects at reduced pressures is an important factor contributing to the death of the insects. El Nahal further showed that the mortality of both *Calandra oryzae* (L.) and *C. granaria* (L.) increased with the exposure period (range 0–8 hr.) and temperature (range 20–28°C.) when the pressure was reduced to between 2 and 8 cm. mercury. Within this pressure range, *C. oryzae* was more susceptible than *C. granaria*, and for both species this susceptibility increased as the pressure was reduced. El Nahal confirmed that when the air in the chamber in which the weevils were contained was kept saturated with moisture, mortality at low pressures was greatly reduced.

Three features of the considerable amount of work reporting the reactions of insects at low pressures seemed to need further investigation. In the first place, of the many workers who have measured the mortality changes which the insects exhibit under varying environmental conditions, only Livingstone & Reed (1940) have measured the actual loss of water from the insects. These authors showed that after 8 hr. at 5 cm. pressure, both adults and larvae of *Lasioderma serricorne* (F.) lost more water in a dry than in a wet atmosphere, and that increasing the partial pressure of oxygen reduced not only the mortality, but also the water loss, from the insects in dry air. A second important consideration is that when the experiments are done in small chambers (of the order of 1 litre volume in El Nahal's experiments) the amount of water lost from the insects is sufficient, at low pressures, to raise the humidity in the chamber to the point at which the subsequent loss is greatly diminished. Two remedies for this difficulty suggest themselves: the use of very large chambers, in which, however, it is difficult to maintain really low pressures for long periods, and the use of humidity-regulating solutions, as adopted in the work reported here.

The third feature requiring consideration is the extent to which the reduced supply of oxygen at low air pressure is responsible for changes in mortality and water loss. Apart from the results of Livingstone & Reed (1940) quoted above, Cotton, Wagner & Young (1937) found that increasing the partial pressure of oxygen at low total pressures materially reduced mortality among their fumigated test insects. This aspect of the problem of the responses of pests to low-pressure conditions is not studied in detail here, although its potential importance must not be forgotten.

Experimental.

The apparatus in which the experiments were carried out, and the breeding and handling of the test insects employed, were substantially the same as those described by El Nahal (1953). Three exceptions need brief mention. The test insects, in paired batches of 50 of each species, were enclosed in small glass tubes about 5–6 cm. long and 1 cm. internal diameter. The ends of the tubes were

* Part of a thesis approved for the degree of Ph.D. of the University of London.

closed with caps of fine wire gauze soldered to metal rings which slipped over the tubes.

The humidifying solutions were absorbed on to cotton-wool plugs contained in open glass tubes of the same dimensions as those holding the insects. Saturated calcium chloride, in the presence of excess salt, was used to maintain about 45 per cent. relative humidity, and a similar preparation of barium chloride gave about 85 per cent. R.H. A dry atmosphere was maintained, when required, by inserting a thin bag of tissue paper containing phosphorous pentoxide. The relative humidity over phosphorous pentoxide is so low that in practice its value will depend on the rapidity with which equilibrium is established. Its value is arbitrarily rated at 0 per cent. for convenience in this paper. The efficacy of these materials was checked in each experiment by including in the chamber a cobalt thiocyanate test-paper (Solomon, 1945), which allows the approximate relative humidity to be determined from the colour of the test-paper.

The water loss from the insects was estimated by direct weighing before and after the exposure to reduced pressures, and the test insects were examined for mortality on the sixth and again on the tenth day after exposure. The data analysed here refer to the count on the tenth day. In each experiment, control batches of both species were kept under conditions differing from the experimental

TABLE I.

Responses of grain weevils to reduced pressures, at different humidities and exposures.

Pressure (cm. mercury)	Exposure period (hr.)	R.H. (%)	<i>C. granaria</i>		<i>C. oryzae</i>	
			Water loss (%)	Mortality (%)	Water loss (%)	Mortality (%)
2	4	Dry	60.4	90	91.7	100
		45	37.1	86	78.7	100
		85	7.8	2	25.6	7
		Not controlled	16.3	0	43.1	96
	8	Dry	87.0	100	99.4	100
		45	57.6	90	88.4	98
		85	11.3	0	40.0	98
		Not controlled	20.2	6	56.7	96
	16	Dry	92.8	100	99.2	100
		45	79.0	94	90.8	100
		85	20.1	48	63.2	96
		Not controlled	29.4	48	67.4	100
4	4	Dry	41.4	90	81.6	100
		45	22.1	14	58.8	100
		85	4.1	0	18.9	18
		Not controlled	12.0	4	37.6	98
	8	Dry	65.7	96	97.2	100
		45	30.9	48	78.8	100
		85	9.6	0	36.0	98
		Not controlled	13.6	0	44.5	100
	16	Dry	85.7	100	98.3	100
		45	42.5	88	91.1	100
		85	16.8	0	44.8	100
		Not controlled	20.5	6	52.1	100
8	4	Dry	14.2	0	37.4	90
		45	6.4	0	16.9	10
		85	2.9	2	8.7	4
		Not controlled	7.6	0	21.6	24
	8	Dry	24.5	14	47.7	98
		45	13.0	0	25.9	50
		85	4.3	0	12.5	0
		Not controlled	10.9	0	26.0	54
	16	Dry	40.7	74	70.3	100
		45	20.1	6	39.0	84
		85	6.1	0	18.2	12
		Not controlled	15.8	0	33.7	78

treatments only in that atmospheric pressure was maintained throughout. In no instance was any material water loss or mortality found in such controls. The test insects were not fed during the treatments, but were weighed and placed on a few grains of wheat after treatment until examined for the mortality response.

Results.

Table I shows the experimental factors and levels selected for investigation. The experimental arrangement was a fully factorial one, involving in all 144 experiments (excluding the controls), in each of which both mortality and water loss were estimated.

A preliminary experiment was done to determine the water content for each species, as estimated by prolonged drying of the insects. Good agreement was found between estimates from insects dried at 150°C. for 6 hr., at 30°C. for 96 hr. at 2 cm. pressure; for 96 hr. over phosphorous pentoxide, or for 44 days over phosphorous pentoxide at atmospheric pressure. The mean values were: *C. granaria*, 53.6 per cent. w/w; *C. oryzae*, 50.1 per cent. w/w. Water loss in Table I is expressed as a fraction of this "available" water content of the insects.

Analyses of variance and covariance were carried out on the two sets of responses shown in Table I. All the main factors proved to be important, confirming in detail the results of El Nahal (1953). Both mortality and water loss increased as the pressure and humidity were lowered, and the water loss was much higher at low pressures and humidities than could be accounted for by the responses to low pressure or low humidity separately. Curiously, however, the mortality under these conditions was almost exactly that predicted from the two separate relations between mortality and pressure, and mortality and humidity.

This discrepancy suggested that not all the changes in mortality under the differing experimental conditions were associated with changes in loss of water, although the two responses are obviously closely related. To test this suggestion, the water loss was used as a concomitant variate in a covariance analysis of the mortality data. None of the main factors induced mortality changes that were not consistent with the associated changes of water loss, although for *C. granaria* there is a suggestion, bordering on statistical significance, that as the humidity is raised mortality declines more rapidly than the water losses.

A nearly linear increase of both responses was found with increase of exposure period, decrease of pressure and decrease of relative humidity. Throughout the experiment, *C. oryzae* is consistently more susceptible to adverse environmental conditions than *C. granaria*, as El Nahal also found, although apart from this

TABLE II.

Responses of grain weevils to very low pressure (3-4 mm. mercury).

Exposure period (hr.)	<i>C. granaria</i>		<i>C. oryzae</i>	
	Water loss (%)	Mortality (%)	Water loss (%)	Mortality (%)
4	5.2	0	5.6	0
6	6.3	4	6.8	2
17	8.9	2	10.5	8
24	15.9	16	13.6	18
48	18.1	26	19.4	40

specific distinction the two insects show very similar reactions to changes in the environment. These findings provide an interesting confirmation of one of the results of El Nahal's analysis of his data. El Nahal found that the interactions between the various factors in his experiments, which were intentionally sacrificed in a Graeco-Latin square design and used as a measure of error, were not significant when assessed against comparisons between replicates. In the much more detailed experiments reported here, few of the interactions are significant, and none are of any importance, compared with the main factors.

A subsidiary experiment was also done, in which pressures rather lower than can normally be sustained in fumigation practice were used. Adults of both species were subjected for up to 48 hr. to a pressure of 3-4 mm. mercury. Again, both water loss and mortality were estimated, and the results are given in Table II.

Comparison of Tables I and II shows that at the lower pressure, both water loss and the mortality of the insects are greatly reduced, and even the specifically greater susceptibility of *C. oryzae* is partly suppressed. For example, after only 4 hr. exposure to 2 cm. pressure (humidity not being controlled), *C. oryzae* lost 43.1 per cent. of its available water, a loss which was associated with a mortality of 96 per cent. of the insects. At 3-4 mm. pressure, however, the water loss only amounted to 5.6 per cent. and all the insects survived.

Discussion.

The main experiment reported above confirms that when the pressure is reduced, the amount of water lost from the insects is sufficient to build up, in the small chambers used in this work, a humidity which materially suppresses further water loss (Table I). Indeed, the effective humidity in chambers without humidity control is shown in Table I to be in the region of 50-80 per cent., and this value was confirmed by the cobalt thiocyanate papers inserted in the chambers. In the absence of insects, these papers were dark green or brown when the pressure was reduced, but changed to blue and eventually pink when the insects were present. The papers in chambers stabilised at 45 per cent. R.H. were blue, those at 85 per cent. were pink. This phenomenon, however, does not seem to have invalidated any of the conclusions of El Nahal (1953) or of Salmond (1953), whose observations agree well with those reported here, as does the work of Livingstone & Reed (1940).

The effect of very low pressures is harder to explain. Moore & Carpenter (1938) found that at 1-2 mm. pressure some, though not all, species of insects were much less susceptible than at 6 cm., and they also made the important observation that sorption of hydrogen cyanide on insects at 1-2 mm. pressure was much less than at 6 cm. Moore & Carpenter attribute this striking change, similar to that reported in the present experiments, to a physical change in the insects, in particular, to collapse of the tracheae. Some physical change seems to be a plausible explanation; the only obvious physiological change would be that associated with a deficiency of oxygen, but Wigglesworth (1935) has shown that, at atmospheric pressure at least, lack of oxygen causes the spiracles to remain open. On the other hand, it is hard to see why a reduction of, say, 755 mm. of a nominal 760 mm. pressure should induce physical changes not produced by a reduction of, say, 730 mm. Levenbook (1951) finds that when the larvae of the Horse Bot-fly, *Gasterophilus intestinalis* (Deg.), are placed in greatly reduced pressures, with the posterior spiracles ligatured, the functional anterior spiracles become non-functional until the pressure is restored. Whatever the cause, however, the phenomenon provides a lower limit of about 2 cm. mercury to the pressure reduction which is economically valuable in fumigations at reduced pressure, using insects such as *Calandra* spp.

Summary.

The water loss and mortality of *Calandra granaria* (L.) and *C. oryzae* (L.) have been studied at low pressures in controlled humidities. The mortality of both species is closely associated with the loss of water under these conditions, a loss which is prevented by a high humidity in the surrounding air. *C. oryzae* is consistently more susceptible than *C. granaria*. Substantially linear relations were observed between water loss and decreasing relative humidity (range 0-85%), increasing period of exposure (range 4-16 hr.), and decreasing pressure (range 2-8 cm. mercury). At lower pressures (3-4 mm. mercury), the water loss and mortality of both species were greatly reduced, suggesting that some physical change had occurred in the insects. A covariance analysis of the mortality response, using the loss of water as a concomitant variate, showed that there was no significant part of the mortality that was not accounted for by the water loss from the insects.

References.

- COTTON, R. T., WAGNER, G. B. & YOUNG, H. D. (1937). Oxygen as a factor in vacuum fumigation.—*J. econ. Ent.*, **30**, p. 560.
- EL NAHAL, A. K. M. (1953). Responses of pests to fumigation. IV. The responses of *Calandra* spp. to reduced pressures.—*Bull. ent. Res.*, **44**, pp. 651-656.
- LEVENBOOK, L. (1951). The effect of carbon dioxide and certain respiratory inhibitors on the respiration of larvae of the horse bot fly (*Gastrophilus intestinalis* de Geer).—*J. exp. Biol.*, **28**, pp. 181-202.
- LIVINGSTONE, E. M. & REED, W. D. (1940). Water vapor as a factor affecting the survival of *Ephestia elutella* and *Lasioderma serricorne* at reduced pressure.—*Ann. ent. Soc. Amer.*, **33**, pp. 583-587.
- MOORE, William & CARPENTER, E. L. (1938). The fumigation of insects with hydrocyanic acid: effect of different air pressures.—*J. econ. Ent.*, **31**, pp. 419-426.
- SALMOND, K. F. (1953). Responses of pests to fumigation. II. Toxicity of hydrogen cyanide to *Calandra* spp. under reduced pressure.—*Bull. ent. Res.*, **44**, pp. 225-230.
- SOLOMON, M. E. (1945). The use of cobalt salts as indicators of humidity and moisture.—*Ann. appl. Biol.*, **32**, pp. 75-85.
- WIGGLESWORTH, V. B. (1935). The regulation of respiration in the flea, *Xenopsylla cheopis* Roths. (Pulicidae).—*Proc. roy. Soc. Lond.*, (B) **118**, pp. 397-419.
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R
NEW SPECIES AND RECORDS OF *DIATRAEA* GUILDING AND
ZEADIATRAEA BOX FROM MEXICO, CENTRAL AND
SOUTH AMERICA (LEPID., PYRAL.).

By HAROLD E. BOX, F.R.E.S., F.R.G.S.

(PLATE XV.)

E.H.A.

Introduction and Acknowledgements.

This paper brings up to date numerous records that have accumulated during the last few years, largely resulting from my travels in Mexico, Central America, Colombia and Peru, including a short trip to Iquitos, on the River Amazon. A few records from Venezuela, additional to those already published in this journal (Box, 1951b), are incorporated, as well as some from other countries for which I am greatly obliged to several valued collaborators.

Dr. R. H. Painter sent me a very complete representative series of moths reared from larvae in maize and sugar-cane in Guatemala, and Mr. L. C. Scaramuzza a similar collection reared mostly from sugar-cane in Mexico. Dr. J. Alex Munro provided me with useful specimens from the Santa Cruz region of Bolivia. From Brazil I have been privileged to examine a very interesting lot of material loaned by Professor Dr. A. da Costa Lima, of the Escola Nacional de Agronomia, Rio de Janeiro; another by Dr. A. G. d'Araujo e Silva, of the Divisão de Defesa Sanitaria Vegetal, Ministério da Agricultura, Rio de Janeiro; and others sent by Dr. C. M. Biezanko, of the Ministério da Agricultura, Pelotas, Rio Grande do Sul. A few additional specimens collected by Dr. Biezanko have been sent to me for study by Dr. Hans Sachtleben, Director of the Deutsches Entomologisches Institut, Berlin. For being able to examine all the specimens of *Diatraea* and *Zeadiatraea* in the very fine collection of Lepidoptera assembled by the late Dr. A. Dampf in Mexico, I am obliged to Dr. J. J. McKelvey, Entomologist of the Rockefeller Foundation, San Jacinto, Mexico City. Certain other smaller collections are referred to in the text.

As stated above, the majority of the records are the result of my own journeys, but nevertheless so much is due to those who accompanied me and helped me in innumerable ways to realize my objectives, that it is a pleasure as well as a duty to mention them by name:

Ingeniero Agrónomo Silverio Flores Cáceres, Entomologist of the Unión Nacional de Productores de Azúcar, Mexico City, who was my constant companion, guide and mentor in almost every journey made in Mexico during two extended visits in 1951 and 1952.

Dr. Paul Berry, Entomologist of the Centro Nacional de Agronomía, Ministerio de Agricultura e Industria, San Salvador, for valued assistance in El Salvador.

Dr. Ralph H. Allee, Director, and the Staff of the Interamerican Institute of Agricultural Sciences, Turrialba, for numerous courtesies and particularly for assistance with transportation, in Costa Rica.

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Mr. Harold R. Shaw, Field Manager, Hacienda La Estrella, Aguadulce, and Mrs. Shaw, for much practical help and personal kindness in the course of several visits to Panama.

Dr. Ciro Molina Garcés, late Secretario de Agricultura, of Cali; and Dr. Adalberto Figueroa P., Professor of Entomology at the Facultad de Agronomía, Universidad Nacional de Colombia, Palmira; for valued assistance in Colombia.

Mr. John Lau, Agronomist at Hacienda Paramonga (W. R. Grace & Co.), Pativilca, for valued assistance in Peru. Mr. Lau was with me and rendered signal service during a brief but not uneventful trip over the Andes to Iquitos and return to Lima.

In Venezuela, Pietro Guagliumi and Pablo Paredes R. were of great assistance, especially in 1953 when a visit was made to the Andean regions of Trujillo and Mérida, and they have shown continued interest in my work on the systematics of *Diatraea* by rearing series of moths and sending them to me from time to time. The drawings here reproduced as figs. 3 and 4 are the work of Signor Guagliumi. I take this opportunity to mention also the name of Dr. Wacław Szumkowski, who has been with me and helped on several field excursions in Venezuela.

Mr. Hahn W. Capps, of the Entomology Research Branch, United States Department of Agriculture, Washington, D.C., very kindly helped with several matters upon which I had the need to consult him, and also sent the photographs shown in the Plate. These photographs were prepared by Mr. Joseph R. Foy, of the Office of Information Service, United States Department of Agriculture, at the United States National Museum, Washington.

Mr. R. G. Fennah, of the Imperial College of Tropical Agriculture, Trinidad, has given me some valuable advice, and also helped in several other ways.

To all those named above, and others mentioned in the text, I offer my most sincere thanks.

A few words on the conditions under which my own collections were made may be of interest. The main object of the field work was to examine the habitats, estimate populations, and collect larvae and pupae from all likely food-plants, as well as cultivated, and rear them to the adult stage for identification. From each new collection, or until familiarity made further collections unnecessary, adequate samples of larvae and pupae were taken and kept as far as possible each in a small salve-tin, the larvae being provided with short cut lengths of the appropriate food-plant. In general practice no assumptions were made as to the identity of a species in a new locality until adults had been reared and dissections made of the genitalia. Quite often, however, reliable determinations were possible by examination of the genitalia dissected from pupae that had died when nearly mature, or from moths emerging completely deformed, which was unavoidable when constantly travelling. Advantage was taken at many places of space and other facilities generously placed at our disposal at agricultural experiment stations and other scientific institutions, but more often than not, especially in Mexico, our car or hotel room had perforce to be our laboratory, where changes of food-plant material were attended to, and recently emerged moths transferred to special containers until their wings had developed.* It is surprising under these circumstances, and it speaks worlds for the conscientiousness of my assistants, that a very high proportion of the moths was reared in perfect condition. So far as actual travelling conditions are concerned, our record was held by the material that Mr. Lau and I collected at Iquitos, which included important series of *Diatraea* larvae and their parasites, whose identity was at first unknown. The

* A useful improvised portable cage consisted of a standard paper drinking-cup, pierced at the sides for ventilation, and covered with a piece of cellophane held in place by an elastic band. About an inch of damp sand was placed in the bottom of the cup to give weight to the rather flimsy contrivance. Pieces of soft paper were provided for the insects to rest upon. Humidity—a real necessity in northern Mexico—was provided by means of a small atomiser used at frequent intervals. For transportation, the cups were arranged in tiers one above the other, in cartons, several dozens to each.

larvae, pupae and Dipterous puparia were collected in the hot steamy "selva" of the Amazon, at a temperature of 105°F. Next day they accompanied us in a non-air-conditioned DC 4, crossing the snow-capped Andes at 20,500 feet with the temperature below freezing point, then to spend five days in the temperate climate of coastal Peru. Some of the moths emerged (mostly deformed) in the hotel at Lima, but others not before I was on the return journey and had arrived back in the tropics at Palmira, in the Cauca Valley of Colombia. After nine days at Palmira, there was a three-day stop-over at Bogotá (8,000 feet elevation), where a few more moths and flies emerged. The last emergences were at my headquarters laboratory at Maracay, Venezuela, four weeks from the date of collection and after a journey of about 3,500 miles mostly by airplane, but considerable distances by railway and motor-car, with numerous packings and unpackings of baggage *en route*. The greatest difficulty was to find suitable wild grasses, which at first were believed to be necessary for the larvae, but it was soon found that these would seldom refuse substituted pieces of sugar-cane or maize stalks (generally available in these parts), and therefore no really important consignments were lost. A lesson learned as a by-product of this interesting experience is that practically all of these Lepidopterous borers in graminaceous plants are to be regarded as potential pests of either sugar-cane or maize or both.

The number of specimens examined in the course of the present study is rather more than 900, the majority of them reared from known food-plants, all Gramineae. They correspond to 21 species of *Diatraea*, some of them extremely rare in museum collections, and four species of *Zeadiatraea*. Three of the *Diatraea* species are described as new to science. In the text that follows, the listing of countries, and divisions within countries, is usually from north to south and then from east to west. In accordance with past practice I record the precise localities, where necessary by reference to better known places shown on standard maps, with the altitudes (approximate, in meters). In each genus the species are arranged in chronological order. References to original descriptions, and synonyms, are omitted as a rule, since the necessary information is readily available in my recent taxonomic papers (see References). The types of the new species have been presented to the British Museum (Natural History). The previously unknown male of *D. instructella* Dyar is presented to the United States National Museum, together with paratypes of *D. balboana*, sp.n. and *D. veracruzana*, sp.n. and representative series of some of the other species dealt with. Other specimens, counted among those examined, have been presented to the Muséum National d'Histoire Naturelle, Paris, the Deutsches Entomologisches Institut, Berlin, and other institutions.

While the title of this paper indicates the records that follow to be new, it is correct to state that some of them have already been published, although this is their first appearance in a systematic paper. Most of the records from Mexico and Peru have appeared in my reports to the organisations which financed my visits to those countries* or in journals devoted to sugar-cane technology rather than entomology. The names of the species concerned with sugar-cane have, with few exceptions, already been given by me (Box, 1953e) but without information as to locality, status, etc., in the countries there named. It is therefore considered convenient to assemble all these records, together with many that have not yet been published, and in the present paper the information given is as complete as possible.

Numerous larval parasites were reared and studied in the course of my work, and it is hoped to deal with them in a separate paper.

* Namely, the Unión Nacional de productores de Azúcar, S.A., Mexico City, and the Comité de Productores de Azúcar, Lima.

DIATRAEA Guilding

Diatraea saccharalis (F.) (*Phalaena saccharalis* Fabricius, 1794).

82 ♂♂, 102 ♀♀. Mexico, Guatemala, El Salvador, (Costa Rica), Panama, Colombia, Peru, Bolivia, French Guiana, Brazil, Uruguay.

42-271 MEXICO, TAMAULIPAS: El Encino (Cañon de Galeana) (150 m.), Xicoténcatl (110 m.), El Mante (90 m.), in sugar-cane (with *magnifactella*), in maize (with *lineolata*), and in cultivated *Sorghum*, iv.1951 and v-vi.1952; El Mante, "caña de azúcar", xii.1930 (A. Dampf); in sugar-cane, x.1950 (L. C. Scaramuzza). SAN LUIS POTOSI: Valle del Rio Naranjo (500 m.), in sugar-cane, iv.1951; Valles del Rio Axtla and Rio Moctezuma between Pujal and Tamazunchale (120-170 m.), in sugar-cane (with *magnifactella* locally), and in maize (with *lineolata*), vi.1952. PUEBLA: Matamoros, x.1935 (Dampf). VERACRUZ: El Higo (50 m.), in sugar-cane, iv.1951 (S. Flores); Jalapa, viii.1934, and Coátepec, no date (Dampf); Coátepec (1050 m.), Xico (1200 m.), Naolinco (975 m.), in sugar-cane (with *magnifactella*), and in maize (with *lineolata*), vii.1952; Fortín (1000 m.), Orizaba (1200-1300 m.), Moyápan (1170 m.), Ciudad Mendoza (1300 m.), in sugar-cane (with *magnifactella*) and in maize, vii.1952; Villa Cardel and Zempoala, near Nautla (sea-level), in sugar-cane (with *magnifactella*), in maize (occasional, with abundant *lineolata*), and in cultivated *Sorghum* (with *evanescens*), vii.1952; Ingenio Paraiso Novillero and a locality 15 kilometers west of Cosamaloapan, Rio Papaloapan (sea-level), in sugar-cane (occasional, with frequent *veracruzana*, sp.n.), and in maize (with *lineolata*), vii.1952; Cosamaloapan (Ingenio San Cristóbal) (sea-level), in sugar-cane, 1953 (A. W. Turner). TABASCO: Tagila, iv.1932, and Frontera, vi.1928 (Dampf). OAXACA: Jiltepec, no date (Dampf). CHIAPAS: Esmeralda, xi.1930, and Tapachula, no date (Dampf). (H. E. Box, except where otherwise stated).

There is a female in the Dampf collection labelled "El Dorado, Sinaloa, 1929", but I very much doubt the accuracy of this locality record, especially as some other specimens in this collection are incorrectly labelled.

Except for the doubtful record from Sinaloa just mentioned, I know of no evidence that *saccharalis* occurs in western Mexico north of Oaxaca State. It was not found by me or my collaborators in more than 130 representative collections of *Diatraea* larvae and pupae, totalling 2,300 specimens, made at numerous localities in Sinaloa, Nayarit and Guerrero during 1951 and 1952. I believe van Zwaluwenburg to be correct when he states (1951, p. 374) that "*D. saccharalis* is not known to occur in Michoacán or in the regions west of that State." In eastern Mexico, the most northerly point where *saccharalis* has been collected, so far as records are known to me, is El Encino, Tamaulipas.* Although the species occurs 350 kilometers farther north, in the lower Rio Grande valley at Brownsville, Texas, I regard the Mexican populations of *saccharalis* to be discontinuous with those of the southern United States, these latter having spread from a focus near New Orleans, Louisiana, where the insect became established by accidental introduction from the Antilles about one hundred years ago (Avequin, 1857). From Tamaulipas southwards, however, the distribution is almost uninterrupted through the ancient maize-growing southern States of Mexico and Central America to the South American continent.

Where *saccharalis* occurs in Mexico the larvae feed indiscriminately in sugar-cane, maize, and to a lesser extent in *Sorghum*, but at present this borer need be reckoned a pest of economic importance only in the large sugar-cane plantations centred around El Mante and Xicoténcatl, Tamaulipas, and even here its damage is very much less than that caused by *D. magnifactella*. The absence of

* This locality is about 40 kilometers south of the Tropic of Cancer (which is crossed by the main highway to Monterrey at Km. 661 from Mexico City) and 130 kilometers south of Ciudad Victoria, Tamaulipas, a town shown on most maps.

saccharalis in wild grasses in any of the localities visited in Mexico is noteworthy, and suggests that this species must have spread northwards in maize in early times, and more recently in sugar-cane.

Male and female moths reared from larvae in maize at Fortín and Orizaba, in the highlands of Veracruz, are larger and of a more orange-yellow colour than usual. They resemble specimens in the British Museum collected at the same localities more than sixty years ago by the Godman-Salvin Expedition, and appear to correspond with the form described as *Diatraea pedidocla* Dyar (1911, p. 211), which was sunk as a synonym of *saccharalis* by Dyar & Heinrich (1927, p. 11).

GUATEMALA: Finca Santa Teresa, 23 kilometers south-west of Guatemala City (1280 m.), in sugar-cane (moderate infestation), v.1951 (*H. E. Box*); Cuyuta (18 m.), Cobán (1320 m.), in maize, viii.1951 (*R. H. Painter*); Antigua (1500 m.) and Finca Pintio, south-west of Antigua, in sugar-cane and maize, viii.1951 (*Painter*).

Published references to *Diatraea* in the Central American countries are so scarce that special attention is drawn to Dr. Painter's interesting observations (1955, p. 40), comparing the incidence of *D. saccharalis* and *D.* (= *Zeadiatraea*) *lineolata* in Guatemala, with notes on their bionomics.

EL SALVADOR: San Andrés (520 m.) and Hacienda Santa Emilia (170 m.), in sugar-cane (moderate infestation), viii.1952 (*H. E. Box*).

(COSTA RICA.) *D. saccharalis* seems to be a great rarity in collections from this country, and I failed to discover it in sugar-cane or maize, or "at light", during my visit in May, 1951, in spite of considerable search at all likely places. Actually, the only positive record known to me is the example in the Paris Museum labelled "Costa Rica, Coll. L. & J. de Joannis" (*Box*, 1948b, p. 420). The moths from "Costa Rica, Irazú, 6000-7000 ft. (*Rogers*)", originally labelled "*Diatraea saccharalis* (Fabr.)" in the Godman-Salvin collection at the British Museum and referred to this species by Druce (1896, p. 295), later proved to be *D. fuscella* Schaus and *D. guatemalella* Schaus (*Box*, 1931, pp. 27-28; 1949, p. 554). Druce's erroneous reference (1896) is undoubtedly the basis of the record by Pittier & Brolley (1897, p. 66) of *saccharalis* in Costa Rica.

I do not recognise as authentic the statements that "Many cosmopolitan insects in Costa Rica—species such as the sugarcane borer (*Diatraea saccharalis*) . . ." and "The sugarcane borer (*Diatraea saccharalis*) is found wherever cane is grown . . ." contained in a semi-popular article by P. Knight (1944), because there is no evidence that specimens were collected and identified. In point of fact, moth borers are *not* important pests of sugar-cane in Costa Rica, but where they occur the one most likely to be found is not *saccharalis*, but *D. tabernella* Dyar, though *guatemalella* appears to be the dominant in one plantation.

PANAMA: Aguadulce (Hacienda La Estrella) (near sea-level), in sugar-cane (very rare, with abundant *tabernella*), and in *Sorghum* growing spontaneously around cane-fields (common), iii.1951 and ii.1952 (*H. E. Box*).

The scarcity of *saccharalis* in sugar-cane in Panama is remarkable. In March, 1951, and February, 1952, among 1,500 *Diatraea* larvae and pupae taken from canes of all ages at the Hacienda La Estrella, only 5 were *saccharalis*, the rest all being *tabernella*.

As in the case of Costa Rica, *saccharalis* is extremely rare in collections from Panama, the only specimen known to me previous to my visit being a female in the Ragonot collection in the Paris Museum, from Chiriquí (*Box*, 1948b, p. 420). The records of *saccharalis* taken at Chiriquí, Volcán de Chiriquí and Bugaba (Druce, 1896, p. 296), are erroneous. The specimens concerned were examined by me at the British Museum in 1930, and all of them proved to be *tabernella* (*Box*, 1931, pp. 26-27; 1949, p. 553).

COLOMBIA, VALLE DEL RIO CAUCA: Cali (1000 m.), one female on window at the international airport, 1.ix.1949; Ingenio Meléndez, near Cali (1150 m.), in sugar-cane; Palmira (1000 m.), in sugar-cane at the Agricultural Experiment Station (with occasional *indigenella*), x.1949 (H. E. Box).

Some interesting observations on this borer in the Cauca Valley, where it is a major pest of sugar-cane, are given by A. Figueroa P. (1954).

PERU, COASTAL REGION (sea-level to c. 60 m.): Chiclayo, Trujillo, and Pativilca, in sugar-cane at all plantations (very abundant), ix.1949; Naña, Rio Rimac, near Lima (50 m.), in maize, ix.1949, and in *Sorghum halepense* in Dr. S. C. Harland's garden, x.1949 (H. E. Box). AMAZONIAN REGION: Huanuco, Rio Huallaga (2000 m.), in sugar-cane, x.1952 (L. C. Scaramuzza); Iquitos (120 m.), in *Euchlaena mexicana* at the Guayabamba Agricultural Experiment Station, and in maize grown by native Indians in forest clearings; south bank of River Amazon at Iquitos, in *Echinochloa polystachya* and *Hymenachne amplexicaulis*; Nanay, near Iquitos, in *Paspalum fasciculatum* (with *albicrinella*), ix.1949 (H. E. Box).

A detailed report on my observations in Peru has been published (1951a). *D. saccharalis* is a major pest in all the coastal plantations, but was not found in sugar-cane at Iquitos, though it is quite common there in maize and in certain wild grass associations. Similar conditions are known on the Lower Amazon (Myers, 1935, p. 338).

BOLIVIA: Santa Cruz, "at light", 20.vi.1953 (J. A. Munro).

Among various moths reared from larvae in sugar-cane in the Santa Cruz region by Dr. Munro, and sent to me for identification, *D. saccharalis* was not represented, all of them proving to be *Eodiatraea rufescens* (Box) (Box, 1953b, p. 180). However, it is to be noted that in a recent paper (Munro, 1954) *saccharalis* is included as a sugar-cane borer at Santa Cruz.

FRENCH GUIANA: Roches des Kourou, "octobre" (Le Moul't, Coll. L. & J. de Joannis, in Paris Museum).

BRAZIL, CEARA: Joaquin Tabora, "lagarta broqueando hastes de arroz", xii.1937 (J. Deslandes). MINAS GERAES: São Gonçalo, "em colmo de arroz", xii.1938 (A. Silva). RIO DE JANEIRO: Campos, Nicteroi, Guaratiba, mostly in sugar-cane, 1934-1950 (Deslandes, A. Grangier, A. Silva, A. Caminho Filho, H. de Souza, J. Gomes); Deodoro, "atacando cana de açúcar" (with *flavipennella*), vii.1934 (A. Azevedo). SANTA CATHARINA: Joinville and Blumenau, vii-viii.1953 (C. M. Biezanko). RIO GRANDE DO SUL: Guarani, iv.1932; Cangussú, iii.1950; Pelotas, various dates 1952-1955 (Biezanko).

URUGUAY, DEP. COLONIA: La Estanzuela, i.1953 (C. M. Biezanko).

***Diatraea impersonatella* (Wlk.)** (*Crambus impersonatellus* Walker, 1863).

22 ♂♂, 19 ♀♀. Venezuela, Peru, Brazil.

VENEZUELA, GUARICO: 15-20 kilometers east of El Sombrero, on road to Chaguaranas (150 m.), in *Paspalum paniculatum* (with *savannarum*) and in *P. virgatum*, in low-lying moist places in orchard savannah, vii-x.1951 (H. E. Box).

PERU, AMAZONIAN REGION: Nanay, near Iquitos (120 m.), in sugar-cane (with *albicrinella* and *Xanthopherne* sp. prob. *bimaculata* Box) planted by native Indians in forest clearings, ix.1949 (H. E. Box).

BRAZIL, RIO DE JANEIRO: Belfort, "en cana de açúcar", ix.1944 (Ch. Robbs); S. Bento, "broça da cana", ii.1942 (A. Silva); Guaratiba, "broqueando capims limao ou c. cidrao" (probably *Cymbopogon citratus* or *C. nardus*), iv.1949 (A. Silva).

These appear to be the first positive records of sugar-cane as a food-plant of

impersonatella in Brazil. The specimen from Belfort (a female) is the actual one illustrated in error as "*Diatraea saccharalis* (Crambinae)" by Dr. A. da Costa Lima (1950, p. 62, fig. 52),* who very kindly sent it to me on loan so that its identity could be verified.

The series from Guaratiba consists of 2 males and 2 females. The fore wing in the males is slightly tinged with some brownish and in the females more evidently so, and these moths tend rather to resemble *angustella* Dyar. Lemon Grass or Citron Grass is a new food-plant record for this species.

I suspect that further study of adequate material from southern Brazil will show *impersonatella* and *angustella* together to form a supraspecies, in the same sense as *busckella* and *rosa* in Venezuela (Box, 1951b, p. 393 foot-note and preceding text), and that two other Brazilian species, viz., *flavipennella* Box and *ragonoti* Box may be components of it. Alternatively, these may prove to be subspecies of *impersonatella*.

***Diatraea tabernella* Dyar (*Diatraea saccharalis tabernella* Dyar, 1911).**

22 ♂♂, 27 ♀♀. Costa Rica, Panama.

COSTA RICA: Cervantes (1350 m.), Juan Viñas (1200 m.) and Grecia (1100 m.), in sugar-cane (light to moderate infestations), v.1951 (H. E. Box).

PANAMA: Aguadulce (Hacienda La Estrella) (near sea-level), in sugar-cane (abundant, with *saccharalis* very rarely), iii.1951 and ii.1952. CANAL ZONE: Summit Gardens, in sugar-cane (scarce), v.1951 (H. E. Box).

This is the dominant sugar-cane borer in the countries named. While it is not a pest of economic importance in Costa Rica, *D. tabernella* reaches serious proportions at the Hacienda La Estrella, Panama, causing considerable damage in cane-fields of all ages.

***Diatraea instructella* Dyar (fig. 1; Plate XV, figs. 1, 2).**

Diatraea instructella Dyar, 1911, Ent. News, 22, p. 201; Dyar & Heinrich, 1927, Proc. U.S. nat. Mus., 71, no. 2691, p. 10, fig. 49; Box, 1931, Bull. ent. Res., 22, p. 22.

Previously known by the unique female type in the United States National Museum (Plate XV, fig. 1), from "Popocatepetl Park, Mexico, July, 1906 (W. Schaus)". Dyar & Heinrich (*l.c.*) give the altitude of this locality as "8-10,000 feet" (= approximately 2450-3050 meters).** A male in the Dampf collection is identified as this species after comparison with the photograph of the female type sent to me by Mr. Hahn W. Capps. The description follows: ♂. Palpus, antenna and head buff. Thorax the same, slightly darker at base of tegulum. Legs pale buff; hind tibia without a prominent tuft of hair-like

* The photomicrograph of the male genitalia shown in the same work (p. 63, fig. 54), however, is correctly attributed to *D. saccharalis*.

** The present main entrance to the Popocatepetl National Park (México State) is on the main road from Cuernavaca and Cuáutla (Morelos) to Chalco (México), though in Schaus' time the best access undoubtedly was by the railway. Señor Flores and I spent some time at this type locality, in a vain search for this rare species, when we passed by there *en route* from Cuernavaca to Tehuacán (Puebla) on 21 June, 1952. My altimeter registered 2360 meters at the Park entrance, which is a close approximation to the round figures given by Dyar & Heinrich, suggesting that Schaus' specimen had been collected not far away, most likely "at light" in a nearby rest-house.

The climate here is temperate and the surroundings are almost pure coniferous forest, chiefly *Pinus* sp. The only promising food-plant of the larva that we saw was maize (which we very thoroughly examined), though it is not improbable that stout grasses of the genus *Tripsacum* grow on the lower slopes of this magnificent extinct volcano. Maize is also the most probable food-plant anywhere near San Jacinto, where Dampf collected the male twenty-five years after the female had been found by Schaus, though other large grasses are almost certainly grown in the nearby Chapultepec Park, also in México City.

scales. Tergum buff, with the proximal two segments yellow-ochreous. Fore wing with the ground colour pale buff, with the veins and interneural lines tinged with fuscous brownish scales; a brownish triangular shaded area near apex; two diagonal rows of dots, consisting of small patches of fuscous-brownish scales on and between the veins, the inner one extending from the dark apical shade in a curve beyond the cell, then widening a little below the cell and reaching to the inner margin near its base; the outer one extending from the apical shade in a wide curve to the inner margin at about half its length from base; a faint yellowish streak from base of cell to outer margin of wing between veins 5 and 6, enclosing a fuscous blackish discocellular dot; a terminal series of minute blackish dots between the veins; cilia pale buff tinged with brownish. Hind wing uniformly whitish tinged with pale buff. Underside of fore wing more or less uniformly buff



Fig. 1.—*Diatraea instructella* Dyar. Male genitalia. a, tegumen, uncus and gnathos; b, aedeagus; c, harpes, vinculum and anellus.

tinged with some brownish, especially along the costa, but without any trace of the pattern of the upperside; of hind wing same as the upperside except for a rather darker area along the length of the costa. Expanse: 36.5 mm.

The frons is moderately prominent, bulging and rounded, rather as in *saccharalis*. The genitalia are shown in fig. 1.

1 ♂. MEXICO, FEDERAL DISTRICT: San Jacinto (Mexico City, 2400 m.), 26.vii.1931 (*A. Dampf*). Presented to the United States National Museum.

D. instructella is a conspicuously large moth, belonging to the same group as *magnifactella* Dyar and *considerata* Heinr., which are also endemic in Mexico.

Diatraea magnifactella Dyar, 1911.

60 ♂♂, 56 ♀♀. MEXICO, TAMAULIPAS: El Encino (Cañon de Galeana) (150 m.), Xicoténcatl (110 m.), El Mante (90 m.), in sugar-cane (with *saccharalis*), iv.1951 and v-vi.1952. SAN LUIS POTOSÍ: Pujal (Ingenio El Tapaón) (100 m.), Valle del Rio Axtla near Tamazunchale (170 m.), in sugar-cane (with *saccharalis*), vi.1952. JALISCO: Acatlán, "caña", vii and viii.1930 (*A. Dampf*); Tamazula, "caña", ix.1936 (*Dampf*). MICHOACAN: Los Reyes (1300 m.), in sugar-cane, 1953 (*A. Ramírez*). MORELOS: Cocoyotla (1160 m.), Xiútepec (800-1200 m.), Cuátula (1250 m.), in sugar-cane (with occasional *muellerella* at Cocoyotla) and also in *Paspalum plenum* at Xiútepec, vii-viii.1952. GUERRERO: near Iguala (750 m.), Hacienda Tepichicotlán, near Chilpancingo (960 m.), Tixtla (1350 m.), in sugar-cane, vii.1952. PUEBLA: Atencingo, no date (*Dampf*); Matamoros (960 m.), in sugar-cane, vii.1952; Tehuacán, in sugar-cane, v.1951 (*D. Ontiveros*); San Juan Ajalpan (1250 m.), 23 kilometers south of Tehuacán, on the old road to Oaxaca, in sugar-cane, vi.1952. VERACRUZ: Teocelo (Ingenio Santa Rosa) (1140 m.), in sugar-cane and one larva (reared to adult) in *Setaria paniculifera* growing on embankment bordering cane-fields; Coátepec (880-1000 m.), Naolinco (975 m.), in sugar-cane, and one larva in maize (with abundant *lineolata*) at

Naolinco, vii.1952; between Las Trancas and El Encero, near Jalapa (1370 m.), in *Paspalum plenum* (occasional, with frequent *veracruzana*, sp.n.); Huatusco (770 m.), Fortín (1000 m.), Orizaba (1200–1300 m.), in sugar-cane (with occasional *saccharalis* locally); Amatlán and other localities near Córdoba (700–750 m.), in sugar-cane (with occasional *saccharalis*), and in *Paspalum virgatum* (with *veracruzana*, sp.n.), vi–vii.1952; El Potrero (280–600 m.), in sugar-cane and in *P. virgatum* (with *veracruzana*, sp.n.), La Providencia and San José de Abajo (350–400 m.), in sugar-cane, vii.1952; Villa Cardel and Zempoala, near Nautla (sea-level), in sugar-cane (with *saccharalis*), vii.1952. (H. E. Box, except where otherwise stated.)

There has been serious confusion in the literature between this species and the closely related *D. considerata* Heinr., which it resembles in both sexes, though the larvae are quite distinct. My statement (1931, p. 29) that “Van Zwaluwenburg’s reference to the occurrence of *D. canella* as a pest of sugar-cane in Mexico (1926, p. 666) is evidently an error for *magnifactella*” should be corrected to read “*considerata*” instead of “*magnifactella*”. It seems that “*D. canella*” was the first identification of some moths reared from larvae in sugar-cane by T. E. Holloway at Villa Unión (Sinaloa) “and probably occurring also in Nayarit” (van Zwaluwenburg, l.c.). These moths were shortly afterwards determined as *magnifactella* by Dyar & Heinrich (1927, p. 14). Heinrich failed to recognise them as conspecific with *considerata* when he described the latter (1931, p. 4) as a new species reared from larvae in sugar-cane by S. E. Flanders at Eldorado (Sinaloa). Van Zwaluwenburg in two recent papers (1949, 1951) mistakenly includes Sinaloa and Nayarit in the distribution of *magnifactella* in Mexico.

Now that I am familiar with all stages of both species in the field and have had opportunities to collect them at their respective type localities, as well as to study long series of reared moths, my conclusion is that all the records from Sinaloa and Nayarit should properly be referred to *considerata*, and that *magnifactella* does not occur in these States, though its known range in western Mexico extends as far north as Acatlán de Juárez (Jalisco).

The series which I have studied exhibits a wide range in coloration in the male, some specimens being pale ochreous or light straw-colour with the hind wing almost whitish, while others are dark brownish with the hind wing almost as dark as the fore wing. These dark-coloured specimens are hard to distinguish from *considerata* except on genitalic characters. The females are more uniformly light straw-coloured, with the hind wing whitish. In both sexes the “*Diatraea* pattern” in the fore wing, consisting of two diagonal rows of fuscous dots passing beyond and then below the cell, generally is conspicuous, though it may be only faintly indicated in old specimens. The female genitalia rather closely resemble those of *considerata*, but those of the male are quite distinct in each species.

The larvae of *magnifactella* feed in sugar-canes of all ages and occasionally cause very serious damage in individual fields. Heavy attacks have been observed in Tamaulipas and Morelos, but elsewhere the infestations appear to be of much lesser intensity.

***Diatraea angustella* Dyar, 1911.**

1 ♂. BRAZIL, RIO GRANDE DO SUL: Pelotas, 18.i.1951 (C. M. Biezanko).

Reference to this species is made in the discussion of *D. impersonatella* on page 761.

***Diatraea bellifactella* Dyar, 1911.**

3 ♂♂. TRINIDAD: Santa Cruz, in *Setaria Poirietiana*, ii–iii.1949 (E. McC. Callan).

This species is very closely related to *balboana*, sp.n. (Panama).

119 376.

14 540

39 431

***Diatraea evanescens* Dyar, 1917.**

18 ♂♂, 23 ♀♀. MEXICO, SINALOA: Villa Unión and Eldorado (near sea-level), in *Paspalum* sp., growing on canal banks and around cane-fields, iv.1951. VERACRUZ: El Potrero, near Córdoba (600 m.), in *Paspalum virgatum* (with *veracruzana*, sp.n.) on edge of cane-field; La Providencia and San José de Abajo (350-400 m.), and near La Tinaja (250 m.), in *P. virgatum* along the highway, vii.1952; Ciudad Alemán (sea-level), in *Paspalum fasciculatum* and *P. virgatum* (with *veracruzana*, sp.n.) on roadside bordering the Rio Papaloapan, vii.1952; Zempoala, near Nautla (sea-level), in cultivated *Sorghum* (with *saccharalis*), vii.1952 (H. E. Box).

D. evanescens has been recorded from North Carolina, South Carolina, Georgia, Mississippi, Missouri, Louisiana, Texas and Guatemala, so that its discovery in two widely separated parts of Mexico is not unexpected.

Previous to being found in *Sorghum* this borer appeared to be confined to various wild species of *Paspalum*. Cartwright (1934, p. 14) records *P. scrobiculatum* as the larval food-plant in South Carolina, and earlier Dyar & Heinrich (1927, p. 18) had cited "*Paspalum larranagai*" (sic) in Louisiana. By the latter is almost certainly intended *P. urvillei* Steud. (syn. *P. larranagai* Arech.) (Hitchcock, 1951, p. 615). According to Hitchcock both *P. scrobiculatum* and *P. urvillei* are introduced in the United States, the former from Asia and the latter from South America, but the species of *Paspalum* harbouring larvae of *D. evanescens* in Mexico are almost certainly indigenous to the region.

***Diatraea guatemalella* Schaus, 1922.**

4 ♂♂, 4 ♀♀. COSTA RICA: Ingenio Turrialba (600 m.), in sugar-cane (moderate infestation), v.1951 (H. E. Box).

Described from Cayuga, Guatemala, and also recorded from Teapa (Tabasco) in southern Mexico. The British Museum has specimens from Costa Rica taken by Champion at "Irazú, 6000-7000 ft.", and one labelled "Costa Rica: Esperanza", a locality that I cannot trace on any map of the country.

***Diatraea postlineella* Schaus, 1922. (Plate XV, fig. 3.)**

1 ♂. MEXICO, VERACRUZ: near Ciudad Alemán, Rio Papaloapan (sea-level), one larva (reared to adult) in maize (with abundant *lineolata*), vii.1952 (H. E. Box). This specimen has been presented to the British Museum (Natural History).

A species previously known by the unique male type (here illustrated) in the United States National Museum, from Quirigua, Guatemala. The Mexican specimen has the "*Diatraea* pattern" of diagonal rows of dots in the fore wing more well-marked, and is somewhat smaller (expanse 25 mm.), than the type (27 mm.), but the very peculiar genitalia (Dyar & Heinrich, 1927, p. 20, fig. 12) render the identification quite sure.

Though differing considerably in coloration and general aspect, the genitalia suggest that *postlineella* has very close affinity with *crambidoides* (Grote) (eastern United States from Long Island, N.Y. south to Florida), and the two species may be grouped together within the genus *Diatraea*. We have here a curious example of discontinuity in two closely related moths, since no similar or allied species have been found in the territory intervening between the ranges of *crambidoides* and *postlineella*.

***Diatraea fuscella* Schaus, 1922.**

4 ♂♂, 3 ♀♀. COSTA RICA: San José (Coll. L. & J. de Joannis, in Paris Museum); Turrialba (600 m.), in *Setaria paniculifera* growing under shade of

trees in the grounds of the Interamerican Institute of Agricultural Sciences, v.1951 (H. E. Box).

Another rare species. Described from Carillo and Guapiles, Costa Rica; also known from "Irazú, 6000-7000 ft.", and Teapa (Tabasco) in southern Mexico.

***Diatraea indigenella* Dyar & Heinrich, 1927.**

3 ♂♂, 4 ♀♀. COLOMBIA, VALLE DEL RIO CAUCA: Palmira (1000 m.), in sugar-cane (occasional, with abundant *saccharalis*) at the Agricultural Experiment Station; Ingenio Meléndez, near Cali (1150 m.), in *Paspalum* sp. (? *virgatum*), growing around cane-fields, x.1949 (H. E. Box).

Judging by available records this species appears to be fairly common in the Cauca valley. It is also recorded from further north, in the province of Choco, but seems to be restricted to western Colombia.

***Diatraea busckella busckella* Dyar & Heinrich, 1927.**

Diatraea busckella Dyar & Heinrich, 1927, Proc. U.S. nat. Mus., 71, no. 2691, p. 16, figs. 5, 53.

Diatraea busckella subsp. *busckella* (Dyar & Heinrich), Box, 1948, Bol. Ent. venezol., 7, p. 36; 1951, Bull. ent. Res., 42, p. 389, figs. 1, 2, pl. xiii, figs. 3, 4, 11.

Forma *busckella* typ.

7 ♂♂, 6 ♀♀. Panama, Venezuela.

PANAMA: Rio Aguacate, near Arraiján (near sea-level), in *Setaria paniculifera* growing on a shady river bank, iii and v.1951. CANAL ZONE: Summit Gardens, in *S. paniculifera* (with *balboana*, sp.n.) on a shady embankment in forest, v.1951 (H. E. Box).

VENEZUELA, TRUJILLO: Valera (400 m.), in *Tripsacum australe* on steep roadside embankment, ii.1953 (H. E. Box).

All of these moths, reared from larvae in wild grass hosts, can be matched by specimens reared from sugar-cane in Venezuela, which I have regarded as typical *busckella busckella* (1951b, p. 389), and with which the male genitalia agree.

Formae incertae.

2 ♂♂, 2 ♀♀. VENEZUELA, TRUJILLO: Betijoque (750 m.), in *Setaria paniculifera* growing among bracken (*Pteris*) in open thickets, ii.1953. MERIDA: El Vigía road, 8 kilometers north of Estanques, Rio Chama valley (650 m.), in *S. paniculifera* growing in a wooded ravine, ii.1953 (H. E. Box).

Only one moth was reared from larvae collected at Betijoque. It is a female agreeing with typical *busckella busckella* in coloration. Larvae were found at the El Vigía road locality in 1947, but no adults were reared from them, so that the determination (as *busckella setariae* Box) was given an interrogation mark in my recent paper on *Diatraea* in northern Venezuela (1951b), and in the map (fig. 2) accompanying it. Now that two males are forthcoming as a result of the second visit made to the same place, in 1953, it can be stated that while slightly darker than typical *busckella busckella* from sugar-cane in Mérida State, they tend to resemble that subspecies rather than *busckella setariae*, especially in the male genitalic characters.

The localities named above are all in the sub-Andine region of Venezuela, where the host-plant, *Setaria paniculifera*, is far from common, occurring in small patches often at considerable distances from each other. For example, Betijoque is 140 kilometers distant from the El Vigía road locality, with intervening mountains reaching to more than 4,500 meters elevation, though there is access by way

of the lowlands along the southern shore of Lake Maracaibo, where, however, the *Setaria* has not been found.

Under such conditions of isolation, well outside the probable range of flight of these moths, and with small chances of local populations mixing with each other (though they may intermix with populations inhabiting nearby sugar-canes), it seems quite logical to expect minor differences in a species already regarded as polytypic (Box, l. c.). As to their origin, it seems just as likely that these small isolated societies of *busckella* may represent survivors of a larger and more widespread past population, as that they have recently migrated to the *Setaria* from fields of sugar-cane, which are nowhere very distant in this region, and nearly always harbour typical *busckella busckella*. This, however, would not have occurred in that part of northern Venezuela inhabited by *busckella setariae*, because *busckella busckella* does not occur there in any of its forms (except the extremely isolated f. *setariaeoides* Box in one restricted locality), its place being taken by the closely related but quite distinct *D. rosa* Heinr. (see map, fig. 2, in Box, 1951b).

While I regard *busckella setariae* as a well-defined allopatric subspecies, at present I do not consider the local sub-Andine populations of *D. busckella* inhabiting *Setaria* as being of higher rank than micro-subspecies, in the sense of Huxley (1942, pp. 201-202). In this category I would also place certain other local populations of *busckella busckella* that were referred to *formae incertae* in my 1951 paper, and which do not appear to match the type or conform with the description. There is no object in attempting to give formal names to these small populations, even were it possible to define them with any sort of precision.

***Diatraea albicrinella* Box, 1931.**

2 ♂♂, 5 ♀♀. PERU, AMAZONIAN REGION: Iquitos (120 m.), in *Andropogon bicornis* (with *Rupela* sp.) in old clearings; Nanay, near Iquitos, in sugar-cane (with *impersonatella* and *Xanthopherne* sp. prob. *bimaculata* Box), planted by native Indians in forest clearings; in *Paspalum fasciculatum* (with *saccharalis*) and in *P. virgatum*, ix.1949 (H. E. Box).

At Iquitos the dominant borer in native Indian plots of sugar-canes grown around their huts in the "selva" was the *Xanthopherne**, but the giant larvae of a *Castnia* were also present. Sugar-cane has been recorded as a host-plant of *albicrinella* at Paraná da Eva, between Itacoatiara and Manaus on the Lower Amazon (Myers, 1935, p. 338), at a distance of nearly 2000 kilometers from Iquitos.

***Diatraea flavipennella* Box, 1931.**

1 ♂, 1 ♀. BRAZIL, RIO DE JANEIRO: Deodoro, "atacando cana da açúcar" (with *saccharalis*), 11.vii.1934 (A. Azevedo). These specimens have been returned to Brazil, where they remain in the collection of the Divisão de Defesa Sanitaria Vegetal, Departamento de Productos Vegetales, Ministerio da Agricultura, Rio de Janeiro.

Previously known only by the type series from Castro (Parana) and Salto Grande, Parapanema (São Paulo). In the present specimens the fore wing of the male is rather more brownish than yellowish; the discocellular and terminal dots are concolorous; expanse 32.5 mm. The female is pale yellowish buff; dots very indistinct; expanse 36.0 mm. The genitalia agree with the figures accompanying the original description.

Reference to this species is made in the discussion of *D. impersonatella* on page 761.

* These larvae failed to survive travelling conditions, and the determination was made from genitalia dissected from pupae, which also died in transit from Iquitos.

Diatraea considerata Heinrich, 1931.

52 ♂♂, 64 ♀♀. MEXICO, SINALOA: Eldorado, v.1932 (A. Dampf); Ingenio Costa Rica, Eldorado, Villa Unión, in sugar-cane, x.1950 (L. C. Scaramuzza); Navolato, Culiacán, Ingenio Costa Rica, Eldorado, Villa Unión (sea-level to c. 60 m.), in sugar-cane (with *grandiosella* and *Chilo loftini* Dyar), iv.1951 and vi.1952. NAYARIT: Tepic, in sugar-cane and maize (rare), x.1950 (Scaramuzza); Tepic (850 m.), Aguirre (600–650 m.), in sugar-cane, in maize (one larva only) and in *Tripsacum lanceolatum*; Ixtlán del Rio (1000 m.), in sugar-cane, iii–iv.1951 (H. E. Box, except where otherwise stated).

D. considerata (especially the female) is very similar to the closely related *magnifactella*, though the larvae are quite distinct. So far as known at present, each of these species has its own particular zone of distribution in Mexico, with no overlapping. *D. considerata* appears to be confined to the western States of Sinaloa and Nayarit, possibly also Jalisco and Colima.*

Observations on this species are given in the reports on my visits to Mexico (1951d, 1953a). *D. considerata* is by far the most destructive of all the sugar-cane borers known to me. In Sinaloa it is a pest of the first magnitude, frequently causing extremely serious damage, up to total loss, in cane-fields of all ages. Sometimes the entire crop may be ruined over areas of several hundred hectares. An account of the accidental introduction of this dangerous insect into the Los Mochis plantation in northern Sinaloa, where it does not occur, and of its prompt eradication, has been published (Box, 1951c).

This is the species referred to as "*D. canella* Hmps." by van Zwaluwenburg (1926, p. 666) and later (Dyar & Heinrich, 1927, p. 14; Box, 1931, p. 29) confused with *magnifactella*; see the discussion of that species on page 763. Now that I know the various stages of *considerata* in the field, I am able to correct my statement (1935, p. 331) concerning the larvae, viz., "small specimens (less than 16 mm. in length) are unspotted and with pronounced lateral stripes along the length of the body." Actually, these longitudinally striped larvae are those of *Chilo loftini* Dyar, a common borer often found in sugar-cane where *considerata* occurs, and which were mixed with the latter when sent to me.

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Diatraea savannarum Box, 1935.

10 ♂♂, 12 ♀♀. VENEZUELA, GUARICO: 15–20 kilometers east of El Sombrero, on road to Chaguaranas (150 m.), in *Paspalum paniculatum* (with *impersonatella*) by roadside in orchard savannah, vii to x.1951. ARAGUA: Maracay (450 m.), at light in house, viii.1950; El Limón, near Maracay, in *Paspalum virgatum* grown at the Experiment Station, vii.1950; northern slope of Rancho Grande-Ocumare road (650 m.), in *P. virgatum* (with *pittieri*; see Box, 1951b, pp. 394–396) by roadside in mountain forest, viii–ix.1950. YARACUY: Nirgua (800 m.), at lights of the electric power plant, overlooking a grassy ravine, v.1949. TRUJILLO: Motatán (350 m.), in *P. virgatum*, viii.1951 (H. E. Box, *P. Guagliumi*, *P. Paredes*).

Because insufficient specimens of both sexes were available at the time, this species was omitted from my 1951 paper, except for mention that it had been collected by R. Lichy at Sanaripe, Amazonas Territory, in southern Venezuela (Box, 1950, p. 245). The new records given above show that *savannarum* has a much wider distribution in Venezuela than had been suspected.

The small whitish larvae feed in the lowest parts of the culms of *Paspalum*, and penetrate deep into the underground rhizomes. One of the female moths

* In my second Mexican report (1953a) records are included of *considerata* in sugar-cane at San Marcos and Tecalitlan (Jalisco), and Quesería (Colima), on the basis of information supplied by Señor Flores. Until specimens from these localities have been positively identified, however, it would be better to regard these records as doubtful, since they could possibly refer to *magnifactella*.

43 200

from near Rancho Grande is much larger than usual (expanse 25.5 mm.). The closest relative of *savannaram* would appear to be *D. gaga* Dyar (Panama).

***Diatraea silvicola* Box, 1951.**

2 ♂♂, 1 ♀. VENEZUELA, YARACUY: Tapia, 30 kilometers east of San Felipe (c. 50 m.), in *Setaria vulpiseta* by roadside in evergreen forest, vii-viii.1951 (H. E. Box).

Previously known only by the type series from near Guasualito (Apure), reared from larvae in the same food-plant in a similar habitat.

***Diatraea colombiana*, sp.nov. (fig. 2).**

Diatraea schausella [nec Dyar & Heinrich, 1927, Proc. U.S. nat. Mus., **71**, no. 2691, p. 24, fig. 19, = *Zeadiatraea schausella* (Dyar & Heinrich), Box, 1955, Proc. R. ent. Soc. Lond., (B) **24**, p. 199, fig. 1], Box, 1931, Bull. ent. Res., **22**, p. 45 (in part, and so far as concerns the ♀ only), pl. iii, fig. 6.

A medium sized light straw-coloured moth, rather similar to females of *D. busckella busckella* Dyar & Heinrich (Panama, eastern Colombia, western Venezuela) but with the pattern in the fore wing intensified and more contrasting, in tawny yellowish instead of brownish lines; also with very distinct genitalia. There is a superficial resemblance to *Zeadiatraea lineolata* (Wlk.), which occurs in the same region as the present species, and also to faded specimens of *Z. schausella* (Dyar & Heinrich) (southern Mexico, Guatemala). However, *D. colombiana*, sp.n. has none of the characters which distinguish *Zeadiatraea* Box, and almost certainly belongs in the same group of *Diatraea* s. str. as *busckella* Dyar & Heinrich and *rosa* Heinrich, though not in the same supraspecies (cf. Box, 1951b, p. 393 foot-note and preceding text).



Fig. 2.—*Diatraea colombiana*, sp. n. Female genitalia.

♀. Palpus, antenna and head pale buff. Thorax the same, darker on a median line and at base of tegulum. Tergum pale buff, proximal two segments yellow-ochreous. Fore wing with the ground colour pale buff, with the veins and inter-neural lines slightly contrasting in shades of yellow, ochreous or tawny, accentuated costally, on a line from base of wing passing above the cell to the apex, on a line from base passing below the cell to the outer margin between veins 4 and 5, on vein 1c for its whole length, and on an elongate area adjacent below vein 1c; a light coloured streak from base of cell to outer margin between

veins 5 and 6, enclosing a small fuscous blackish discocellular dot; a terminal series of small fuscous blackish dots between the veins on outer margin. Hind wing uniformly whitish. Underside of fore wing dull ochreous with the pattern of the upperside faintly indicated; of hind wing similar to upperside. Expanse: 31.5 mm.

The frons is moderately prominent, conically produced, with a rather blunt (spatulate) apex. The genitalia (fig. 2) are of similar general construction to *rosa* Heinrich (Box, 1951b, fig. 1) but differ in the shape and proportions of the papillose-setose lobes in front of the genital opening and of the chitinised rim or shield below it.

Holotype ♀. COLOMBIA, Choko (*i.e.*, Choco) Prov.: Condoto (*H. G. F. Spurrell*). I am very much obliged to Mr. N. D. Riley and Mr. W. H. T. Tams for kindly sending this specimen on loan for me to re-examine. It has been returned to the British Museum (Natural History).

Reference to my earlier misidentification of this moth (1931, *l. c.*) is made in my discussion (1955, *l. c.*) of *Zeadiatraea schausella* (Dyar & Heinrich).

***Diatraea balboana*, sp. nov.** (fig. 3 & Plate XV, fig. 4).

A medium sized yellowish straw coloured moth, the sexes similar to each other. Fore wing with two diagonal "lines" as in *saccharalis* but more prominent. Closely related and quite similar to *bellifactella* Dyar (Grenada, Trinidad, Brazil, Bolivia), which lives in a similar habitat, but differing in the characters of the genitalia.

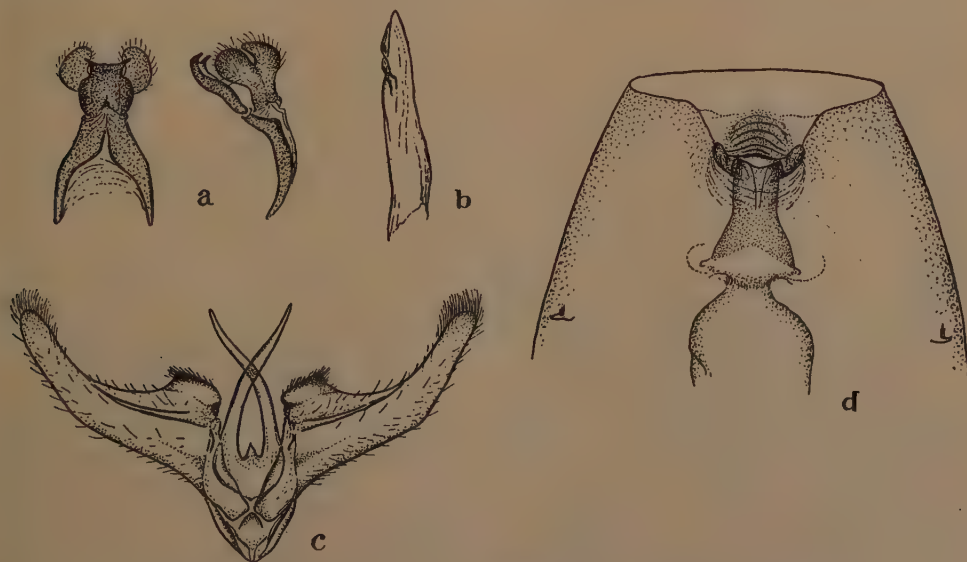


Fig. 3.—*Diatraea balboana*, sp. n. Genitalia. a, ♂, tegumen, uncus and gnathos; b, ♂, aedeagus; c, ♂, harpes, vinculum and anellus; d, ♀.

♂, ♀. Palpus pale buff, tinged with brownish at sides and below. Antennal shaft yellowish, with pale buff scales. Head and thorax pale buff with a narrow median darker line; tegulum pale buff tinged with light brownish. Legs pale buff. Tergum pale buff tinged with brownish except on apical two segments, which are whitish tinged with pale buff, and the proximal two segments, which are aureous. Venter whitish tinged with pale buff. Fore wing with the ground colour whitish tinged with pale buff, with the veins and interneural lines clothed with darker

scales, which are yellowish or tawny around the cell and beyond to the outer margin, more brownish and tending to coalesce on the costa and inner margin; an elongated light yellowish streak surrounding the cell and extending beyond to the outer margin between veins 5 and 6; a small black discocellular dot; a terminal row of small blackish dots between the veins on outer margin; two diagonal lines composed of small elongated groups of fuscous brownish scales on and between the veins, the inner one from a triangular shaded area at apex to just beyond the cell and thence continuing almost straight to the inner margin near its base, this line tinged with yellowish or tawny scales where it passes beyond the cell; the outer line narrower, shorter, extending from near apex of vein 7 on outer margin to vein 2 and thence in a gentle curve inwards to the inner margin halfway between vein 1c and the base of the wing. Cilia pale buff slightly tinged with brownish. Hind wing opalescent pale buff, slightly tinged with some brownish at apex; an irregular subterminal row of small fuscous dots or streaks on outer margin; cilia pale buff. Underside of fore wing pale buff strongly overlaid with brownish except on the costa, on the elongated streak enclosing the cell, and subterminally; discocellular dot faint; terminal dots prominent; of hind wing similar to upperside. Expanse: ♂, 27.0–28.0 mm.; ♀, 28.0–35.0 mm.

The frons is produced conically, with a prominent sharp apex. The second abdominal segment of the male bears lateral retractile processes each consisting of a small tuft or brush of short stiff hair-like scales. The genitalia of both sexes are figured.

Holotype ♂, allotype ♀, paratypes 2 ♂♂, 2 ♀♀. PANAMA, CANAL ZONE: Summit Gardens, reared from larvae boring in stalks of *Setaria paniculifera* (with *busckella busckella*), growing on side of stream under forest trees, 22.v.1951 (H. E. Box); same data, 5 and 11.x.1951 (S. Flores). Paratypes presented to the United States National Museum and the Deutsches Entomologisches Institut.

***Diatraea veracruzana*, sp. nov.** (fig. 4 & Plate XV, figs. 5, 6).

A moderately large moth for the group. The fore wing light brownish (♂) or pale straw colour (♀), with the diagonal rows of dots forming the "*Diatraea* pattern" distinct but not prominent (♂) or very faintly indicated (♀). The

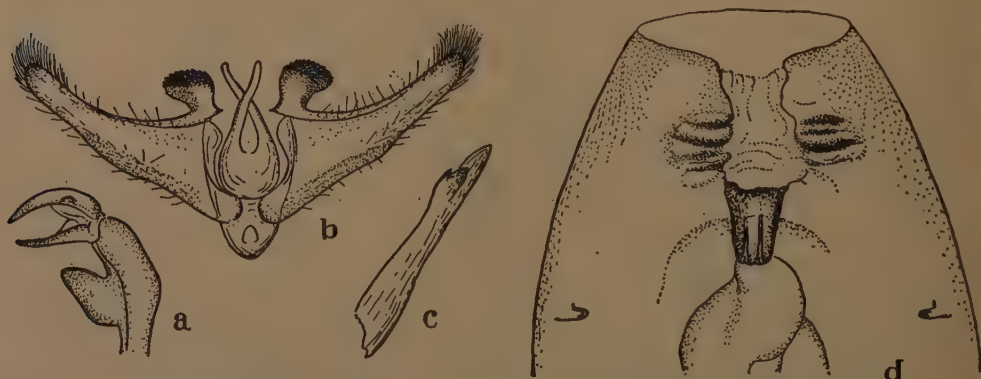


Fig. 4.—*Diatraea veracruzana*, sp. n. Genitalia. a, ♂, tegumen, uncus and gnathos; b, ♂, aedeagus; c, ♂, harpes, vinculum and anellus; d, ♀.

closest relative appears to be *guatemalaella* Schaus (southern Mexico, Guatemala, Costa Rica).

♂. Palpus and antenna brownish buff. Head and thorax more or less uniformly brownish buff, slightly darker on tegulum. Legs pale buff. Tergum whitish tinged with pale buff except on apical segment, proximal two segments dark

yellowish or tawny. Venter opalescent whitish. Fore wing with the ground colour pale buff, with the whole surface closely and finely suffused with brownish-tipped scales arranged in close-ranked lines, giving a light brown tinge to the wing, this suffusion less pronounced in an elongate area surrounding the cell and produced slightly beyond it between veins 5 and 6; a small blackish discocellular dot, sometimes almost obsolete; a terminal series of minute blackish dots on and between the veins; two diagonal rows of faintly indicated patches of fuscous scales forming dots or short streaks on the veins, the outer row from an indistinct shaded area at apex of wing, in a curve beyond the cell, then widening to become a distinct shaded area below the cell and continuing in a wide curve to near base of the wing; the outer row composed of elongated dots on the veins, in a wide curve from vein 7 half-way between apex of cell and outer margin of wing, to vein 1c at a point on the inner margin about two-thirds its length from the base of the wing; cilia light brownish tipped with pale buff. Hind wing opalescent whitish somewhat tinged with buff subterminally; an interrupted series of fuscous dots or streaks forming an indistinct line along the outer margin subterminally; cilia whitish. Underside of fore wing pale buff tinged with brownish, the veins and interneural lines contrasting in a darker shade but without traces of the diagonal rows of dots; discocellular dot faint; terminal series of small blackish dots distinct; of hind wing similar to upperside but tinged with buff on costa and at apex. Expanse: 30.0-31.5 mm.

♀. Larger and lighter in colour. Fore wing pale straw colour without any trace of brownish, with the diagonal rows of dots faint and indistinct. Expanse: 34.0-38.0 mm.

The frons is rounded and slightly protuberant. The second abdominal segment of the male bears lateral retractile processes each consisting of a small brush of hair-like scales. The genitalia of both sexes are figured.

16 ♂♂, 15 ♀♀. MEXICO, VERACRUZ: Holotype ♂, allotype ♀: Teocelo (Ingenio Santa Rosa), near Coátepec (1110-1140 m.), reared from larvae boring in stalks of *Paspalum plenum* and *P. virgatum*, 8.vii.1952 (H. E. Box). Paratypes: Coátepec (850-1000 m.), in *P. plenum*; between Las Trancas and El Encero (1370 m.), near Jalapa, in *P. plenum* (with occasional *magnifactella*); Huatusco (770 m.), in *P. virgatum*; Amatlán (750 m.) and El Potrero (600 m.), near Córdoba, in sugar-cane (with *magnifactella*) and in *P. virgatum* (with *magnifactella* and *evanescens*); La Providencia and San José de Abajo (350-400 m.), in *P. virgatum*; Ciudad Alemán, in *Paspalum fasciculatum* (with *evanescens*) and in *P. virgatum*, by roadside bordering the Rio Papaloapan (sea-level); Ingenio Paraíso Novillero, 24 kilometers east of Ciudad Alemán (sea-level), in sugar-cane (frequent, with occasional *saccharalis*); Cosamaloapan (Ingenio San Cristóbal), Rio Papaloapan (sea-level), in sugar-cane; all 26.vi-16.vii.1952 (H. E. Box). Paratypes presented to United States National Museum and Deutsches Entomologisches Institut.

It is strange that this fine and distinctive moth, the larva of which is a common sugar-cane borer over considerable areas in Veracruz, including the large plantations at El Potrero and San Cristóbal, should have escaped previous notice. The species has a wide altitudinal as well as geographical distribution in Veracruz, and is evidently endemic in this part of Mexico.

ZEADIATRAEA Box

Zeadiatraea Box, 1955, Proc. R. ent. Soc. Lond., (B) 24, p. 197.

Zeadiatraea lineolata (Wlk.) (*Leucania lineolata* Walker, 1856).

36 ♂♂, 51 ♀♀. Mexico, Guatemala, El Salvador, Nicaragua, Costa Rica, Netherlands Guiana.

MEXICO, ZACATECAS (close to boundary with DURANGO): near Sombrete (2100 m.), old borings and pupa-cases in dried maize stalks, iv.1951. TAMAULIPAS: El Encino (Cañon de Galeana) (150 m.), Xicoténcatl (110 m.), El Mante (90 m.), in maize (with *saccharalis*), iv.1951 and v-vi.1952. SAN LUIS POTOSI: Santa Barbarita, 20 kilometers east of Ciudad del Maíz (1200 m.), in old dry maize stalks, iv.1951; Pujal (100 m.), in maize, iv.1951 (*S. Flores*); Valles del Rio Axtla and Rio Moctezuma between Pujal and Tamazunchale (120-170 m.), in maize (with *saccharalis*), vi.1952. MICHOACAN: Los Reyes (1300 m.), in maize, 1953 (*A. Ramirez*). PUEBLA: Tehuacán, ix.1927 (*A. Dampf*); San Juan Ajalpan (1250 m.), 23 kilometers south of Tehuacán, on the old road to Oaxaca, in maize (with *grandiosella*), iv.1952. VERACRUZ: Xico (1200 m.), in maize (with *saccharalis*), and Naolinco (975 m.), near Jalapa, in maize (with *magnifactella*), vii.1952; Córdoba (750 m.), Amatlán (700 m.), El Potrero (600 m.), La Providencia (400 m.), in maize (with *saccharalis* locally), vi-vii.1952; Zempoala, near Nautla (sea-level), in maize (with *saccharalis*); Veracruz, "maíz", 1929 (*Dampf*); Ciudad Alemán, Rio Papaloapan (sea-level), in maize (with *postlineella*), vii.1952; 14 kilometers west of Cosamaloapan, Rio Papaloapan (sea-level), in maize (with *saccharalis*), vii.1952; San Andrés Tuxtla, "maíz", 1930 (*Dampf*). CHIAPAS: Huixtla, near Tapachula, xi.1932 (*Dampf*). CAMPECHE: La Joya, in maize, x.1950 (*L. C. Scaramuzza*). QUINTANA ROO: Payo Obispo (now Ciudad Chetumal) and Zacaleca, viii.1925 (*Dampf*). (*H. E. Box*, except where otherwise stated.)

This species is conspicuously absent in collections from the northern and north-western States of Mexico, where it is replaced by *grandiosella* Dyar. It was not found among large numbers of larvae from maize in the course of my own investigations in Sinaloa, Nayarit, Morelos and Guerrero. The early references of van Zwaluwenburg (1926, p. 666) and others (see Box, 1931, pp. 44, 46) to *lineolata* as an important sugar-cane borer in Mexico are known errors for *grandiosella*.

GUATEMALA: Tiquisate (70 m.), Cobán (1320 m.), Barcena (1480 m.), Antigua (1500 m.) and Finca Pintio, near Antigua, in maize and teosinte (*Euchlaena mexicana*), viii.1951 (*R. H. Painter*).

A valuable contribution to our knowledge of the bionomics of *Z. lineolata* appears in the recent paper by Dr. Painter (1955, p. 40), where he summarises his observations in Guatemala and compares the larval habits of this species with *D. saccharalis*.

EL SALVADOR: San Andrés (520 m.), in maize, viii.1952 (*H. E. Box*).

NICARAGUA: La Calera, Managua, "Corn (in stems)", no. 278, 6.viii.1953 (*R. B. Swain*).

This record refers to a specimen in the United States National Museum, and I am most obliged to Mr. Capps for communicating the full data concerning it. The specimen reared by the late Dr. Ralph B. Swain is believed to constitute the first record of this species in Nicaragua.

COSTA RICA: San José, viii.1895 (Coll. L. & J. de Joannis, in Paris Museum; probably collected by *H. Pittier*); southern slopes of Volcan Irazú above Cartago (1750 m.), in old dry maize stalks, v.1951 (*H. E. Box*).

NETHERLANDS GUIANA: Lelydorp, "uit mais", v.1951 (*D. C. Geijskes*). Dr. F. J. Simmonds kindly sent me a series of specimens reared by Dr. Geijskes in Surinam.

***Zeadiatraea grandiosella* (Dyar) (*Diatraea grandiosella* Dyar, 1911).**

24 ♂♂, 30 ♀♀. MEXICO, CHIHUAHUA: Chihuahua and Ciudad Camargo, "maíz", vii.1929 and vii.1931 (*A. Dampf*). SINALOA: Los Mochis, in sugar-cane

(with *Chilo loftini*) and at light, x.1950 (*L. C. Scaramuzza*); San Blás and Los Mochis (near sea-level), in sugar-cane (with *C. loftini*), Guamuchil and Perico (30–50 m.), in maize (with *Chilo* sp.), iv.1951; Navolato, Culiacán, Ingenio Costa Rica (near sea-level), in sugar-cane (with *C. loftini* and abundant *D. considerata*) and in maize, iv.1951 and vi.1952. FEDERAL DISTRICT: San Jacinto (Mexico City, 2400 m.), vii.1931 (*Dampf*). MORELOS: Hacienda Palmira, near Cuernavaca (1200 m.), in maize, vii.1952. PUEBLA: San Juan Ajalpan (1250 m.), 23 kilometers south of Tehuacán, on the old road to Oaxaca, in maize (with *lineolata*), iv.1952. VERACRUZ: see text below. (*H. E. Box*, except where otherwise stated.)

The type locality is Guadalajara (Jalisco), altitude 1580 m.

In Mexico *Z. grandiosella* is widely distributed as a borer in maize, except in the southern States, but as a pest of sugar-cane it would seem at the present time to be restricted to Sinaloa. There is, however, the record of F. W. Ürich (1913), who cites *grandiosella* as a sugar-cane borer at "Santa Lucrecia, State of Vera Cruz", with H. G. Dyar as authority for the determination (as *Diatraea grandiosella* Dyar).

Mr. Capps has gone to considerable trouble to see whether Ürich's specimens could be traced in the United States National Museum, and he very kindly allows me to quote from his letter to me (October 21, 1955): "I am sorry but my search for specimens or information relating to the Ürich paper failed to develop anything. I checked both the larval and adult collections of all the species of *Diatraea* but could not find any specimens that could be associated with it. I also went through the Dyar correspondence file and found no letter referring to them or their disposition. It does seem strange indeed, in view of Dyar having supplied the determination and description of the larva used in the Ürich article that the locality (Santa Lucrecia, Veracruz, Mexico) was not among those listed for the distribution of *grandiosella* by Dyar and Heinrich (1927, p. 26) and also that Veracruz was cited in a paper a few years later by E. G. Davis et al. (1933, p. 3), yet there are no specimens of *grandiosella* from Veracruz in the collection here."

As there is some uncertainty whether *grandiosella* occurs in Veracruz, I have carefully gone over my series from Mexico and find that I had misidentified several specimens which are actually *lineolata* (Wlk.), so that my references to *grandiosella* at "Veracruz: El Potrero (600–750 m.); Córdoba (800–950 m.); Jalapa (1000–1250 m.) (1953a, p. 7) and "it also attacks maize . . . as far south . . . as Veracruz" (1955, p. 198), require to be corrected. Nevertheless, Veracruz will have to remain in citing the distribution of this species, on the basis of Ürich's record from Santa Lucrecia,* however circumstantial this may now appear, and the apparently independent evidence provided in the paper by Davis & others, which I have seen.

Zeadiatraea schausella (Dyar & Heinrich) (*Diatraea schausella* Dyar & Heinrich, 1927).

Since writing my 1955 paper I have received additional specimens as follows:—2 ♂♂, 3 ♀♀. MEXICO, VERACRUZ: near Córdoba (800 m.), in *Setaria Poirietiana*, viii.1953 (*A. Ramírez*).

Zeadiatraea muellerella (Dyar & Heinrich) (*Diatraea muellerella* Dyar & Heinrich, 1927).

Detailed records were not given in my 1955 paper and are therefore presented below.

* The Oxford Atlas (O.U.P., 1951) shows Santa Lucrecia about the middle of the Isthmus of Tehuán-tepec, 100 kilometers south-west of Minatitlán (Veracruz) and 100 kilometers north of Tehuán-tepec (Oaxaca). Señor Flores told me that the name Santa Lucrecia has been altered to Jesús Carranza, under which name the town is shown on recent maps of Mexico. It is approximately 280 kilometers distant from Tehuacán (Puebla), the nearest place where *grandiosella* has been recently collected and positively identified.

7 ♂♂, 13 ♀♀. MEXICO, MORELOS: Cuernavaca (1500 m.), ii.1932 (*A. Dampf*); Cuáutla (1260 m.), in maize, viii.1952 (*S. Flores*); 10 kilometers south of Yaútepec, on road to Zacátepec (1200 m.), in maize, viii.1952 (*H. E. Box*); Ingenio Cocoyotla, 34 kilometers south-west of Cuernavaca, on road to Miacatlán, in sugar-cane (one larva (reared) with abundant *magnifactella*), viii.1952 (*Box*). GUERRERO: Iguala, 1932 and viii.1935 (*Dampf*); Iguala (750 m.), in maize, vii.1952 (*Box*); Zumpango, viii.1935 (*Dampf*); Colótlepec, Mochitlán and Tixtla, near Chilpancingo (800–1350 m.), in maize, vii.1952 (*Box*) and ix.1952 (*Flores*).

Summary.

Records are given of the localities (with altitudes) of approximately 900 specimens representing 21 species of *Diatraea* Guild. and four species of *Zeadiatraea* Box, from Mexico, Central and South America. Most of the moths were reared from known food-plants (all Gramineae) and the larvae of several of them are important agricultural pests as stalk-borers in sugar-cane and maize.

Three species of *Diatraea* are described as new to science and their genitalia are figured, viz., *colombiana*, sp.n. (Colombia), *balboana*, sp.n. (Panama) and *veracruzana*, sp.n. (Mexico). The previously unknown male of *D. instructella* Dyar (Mexico) is described and its genitalia figured. These moths (except *colombiana*) are illustrated in the Plate. An attempt is made to clarify the confusion which has existed concerning *D. magnifactella* Dyar and the closely related *D. considerata* Heinrich, both of which are endemic in Mexico, but each with its own area of distribution without overlapping. The paper includes additional records and observations on the polytypic *D. busckella* Dyar & Heinrich and certain of its subspecies in Panama and Venezuela, previously discussed by the writer in this journal in 1951.

References.

- AVEQUIN, J. B. (1857). Des ennemies de la canne à sucre ou les insectes qui attaquent la canne à sucre dans les Antilles et en Louisiane.—*J. Pharm. Chim.*, Paris, (3) **32**, pp. 335–337.
- Box, H. E. (1931). The Crambine genera *Diatraea* and *Xanthopherne* (Lep., Pyral.).—*Bull. ent. Res.*, **22**, pp. 1–50.
- Box, H. E. (1935). New records and three new species of American *Diatraea* (Lep., Pyral.).—*Bull. ent. Res.*, **26**, pp. 323–333.
- Box, H. E. (1948a). Notes on the genus *Diatraea* Guilding (Lepid., Pyral.). Introduction and parts I, II and III.—*Bol. Ent. venezol.*, **7**, pp. 26–59.
- Box, H. E. (1948b). Report upon specimens of *Diatraea* Guild. in the Paris Museum, with the description of a new species from Brazil (Lep., Pyral.).—*Rev. Ent.*, Rio de J., **19**, pp. 419–422.
- Box, H. E. (1949). Notes on the genus *Diatraea* Guilding (Lepid., Pyral.). Parts IV and V.—*Rev. Ent.*, Rio de J., **20**, pp. 541–555.
- Box, H. E. (1950). Report upon specimens of *Diatraea* Guilding (Lepidoptera, Pyralidae) in the Cornell University Collection.—*J. N.Y. ent. Soc.*, **58**, pp. 241–245.
- Box, H. E. (1951a). Observations on the Sugar-cane Moth Borer, *Diatraea saccharalis* (Fabr.) in Peru.—*Proc. 7th Congr. int. Soc. Sug. Cane Tech.*, pp. 328–343. (*Rev. appl. Ent.*, (A) **39**, p. 430.)
- Box, H. E. (1951b). New species and records of *Diatraea* Guild. from northern Venezuela (Lepid., Pyral.).—*Bull. ent. Res.*, **42**, pp. 379–398.

- Box, H. E. (1951c). A major pest intercepted and destroyed in western Mexico.—Sugar, N.Y., **46**, no. 10, pp. 47, 49.
- Box, H. E. (1951d). Informe preliminar sobre los barrenadores o "borers" de la caña de azúcar (*Diatraea*, *Chilo*) en México, a base de un viaje de reconocimiento efectuado durante marzo-abril, 1951, a las regiones cañeras: I Sinaloa, II Nayarit, y XIV Huasteca; con observaciones complementarias.—93 pp. Mexico, D.F., Un. nac. Prod. Azúc. (R.A.E., (A) **39**, p. 431.)
- Box, H. E. (1953a). Informe sobre las plagas insectiles que atacan a la caña de azúcar en México, a base de un viaje de reconocimiento efectuado durante mayo-julio, 1952, a las regiones cañeras: I Sinaloa, VI Balsas, VII Tehuacán, VIII B Papaloapan, XII Veracruz central, XIII Costa de Veracruz y XIV Huasteca.—Bol. azúc. mex., no. 44, suppl., 26 pp. (R.A.E., (A) **43**, pp. 220-222.)
- Box, H. E. (1953b). New Crambine genera allied to *Diatraea* Guilding (Lepidoptera: Pyralidae). I.—Proc. R. ent. Soc. Lond., (B) **22**, pp. 178-180.
- Box, H. E. (1953c). List of sugar-cane insects.—101 pp. London, Commonw. Inst. Ent.
- Box, H. E. (1955). New Crambine genera allied to *Diatraea* Guilding (Lepidoptera: Pyralidae). III.—Proc. R. ent. Soc. Lond., (B) **24**, pp. 197-200.
- CARTWRIGHT, O. L. (1934). The Southern Corn Stalk Borer in South Carolina.—Bull. S. C. agric. Exp. Sta., no. 294, 32 pp.
- DAVIS, E. G., HORTON, J. R., GABLE, C. H., WALTER, E. V. & BLANCHARD, R. A. (1933). The Southwestern Corn Borer.—Tech. Bull. U.S. Dep. Agric., no. 388, 61 pp.
- DRUCE, H. (1896). Biologia Centrali-Americana. Insecta, Lepidoptera-Heterocera, **2**, pp. 295-296.
- DYAR, H. G. (1911). The American species of *Diatraea* Guilding (Lepid., Pyralidae).—Ent. News, **22**, pp. 199-207.
- DYAR, H. G. & HEINRICH, C. (1927). The American moths of the genus *Diatraea* and allies.—Proc. U.S. nat. Mus., **71**, no. 2691, 48 pp.
- FIGUEROA P., A. (1954). The sugar-cane entomology of the Cauca valley of Colombia.—Proc. 8th Congr. int. Soc. Sug. Cane Tech., pp. 568-569.
- HEINRICH, C. (1931). Notes on and descriptions of some American moths.—Proc. U.S. nat. Mus., **79**, no. 2879, 16 pp.
- HITCHCOCK, A. S. (1951). Manual of the grasses of the United States. Revised by A. Chase.—Misc. Publ. U.S. Dep. Agric., no. 200 (2nd edn.), 1051 pp.
- HUXLEY, J. (1942). Evolution: the modern synthesis.—645 pp. London, Allen & Unwin.
- KNIGHT, P. (1944). An entomologist looks at Costa Rica.—Agric. Americas, **4**, pp. 203-208, 217-218.
- LIMA, A. DA COSTA. (1950). Insetos do Brasil, **6**, Lepidópteros. 2a. parte.—420 pp. [Rio de Janeiro.]
- MUNRO, J. A. (1954). Entomology problems in Bolivia.—FAO Plant Prot. Bull., **2**, pp. 97-101.
- MYERS, J. G. (1935). The ecological distribution of some South American grass and sugar-cane borers (*Diatraea* spp., Lep., Pyralidae).—Bull. ent. Res., **26**, pp. 335-342.

- PAINTER, R. H. (1955). Insects on corn and teosinte in Guatemala.—J. econ. Ent., **48**, pp. 36-42.
- PITTIER, H. & BIOLLEY, P. (1897). Invertebrados de Costa Rica. III. Lepidópteros Heteróceros.—66 pp. San José, C.R., Inst. fis. geograf. nac.
- URICH, F. W. (1913). Notes on some Mexican sugar cane insects from Santa Lucrecia, State of Vera Cruz . . .—J. econ. Ent., **6**, pp. 247-249.
- VAN ZWALUWENBURG, R. H. (1926). Insect enemies of sugarcane in western Mexico.—J. econ. Ent., **19**, pp. 664-669.
- VAN ZWALUWENBURG, R. H. (1949). Insects and other pests of sugarcane.—Rep. Sug. Ind. Mex., **2**, appdx. B, 74 pp.
- VAN ZWALUWENBURG, R. H. (1951). The insects affecting sugar cane in Mexico.—Proc. 7th Congr. int. Soc. Sug. Cane Tech., pp. 373-377.
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Diatraea ($\times 2$) in the United States National Museum.

FIG. 1. *D. instructella* Dyar ♀ holotype. FIG. 2. *D. instructella* Dyar ♂. FIG. 3. *D. postlineella* Schs. ♂ holotype. FIG. 4. *D. balboana* sp. nov. ♀ paratype (the ♂ is similar). FIG. 5. *D. veracruzana* sp. nov. ♂ paratype. FIG. 6. *D. veracruzana* sp. nov. ♀ paratype.

MANDIBULAR LENGTH IN *NUPSERHA BICOLOR* THOMS. SSP.
POSTBRUNNEA BREUN. (COL., LAMIIDAE) AS THE FACTOR
 IN DETERMINING THE SITE OF OVIPOSITION IN
CORCHORUS OLITORIUS.

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(PLATE XVI.)

Nupserha bicolor Thoms. ssp. *postbrunnea* Breun. was recently reported (Dutt, 1952, 1954) as a serious pest of jute, *Corchorus olitorius*. The ovipositing female is the destructive stage of the pest. The larva feeds upon the pith tissues and moves along the hollow of the pith. In *olitorius* jute, the pith disintegrates early, resulting in the formation of a hollow or a partly hollow central region. Feeding on the dead pith tissues by the larva has, therefore, no visible adverse effect on the host-plant, which can grow well with the borer inside. The borer never tunnels through the woody tissues or the fibre layers, and therefore there is no interference with growth and development.

Damage.

The adult female of *N. bicolor* ssp. *postbrunnea* girdles the stem with its mandibles at two different levels preparatory to laying an egg between the two rings so cut. The damage thus caused results in the withering and ultimate death of the apical portion of the plant above the ring cut (Pl. XVI, fig. 1). As yield of jute fibre is obtained from the vegetative body and because the vegetative growth period is limited to about three and a half months, any loss of stem length, together with the growing point, has an adverse effect on the fibre yield. The loss of stem length in the C.G. variety of *olitorius* jute by girdling at different stem-diameter levels is indicated in Table I. A loss of stem length of from 10 to 20 cm. is the most frequent, while girdling is most frequent at a point where the diameter of the stem falls within the range of 0.26 cm. to 0.30 cm.

TABLE I.

Frequency distribution of loss of stem length due to girdling at different stem-diameter levels.

Stem-diam. classes (cm.) at level of lower ring	Loss of stem length from lower ring to tip (cm.)										Total
	0-5	5.1-10	10.1-15	15.1-20	20.1-25	25.1-30	30.1-35	35.1-40	40.1-45	45.1-50	
0.2-0.25 ..	2	30	82	80	37	5	1	1	0	1	239
0.26-0.30 ..	1	36	206	203	113	32	11	—	2	—	604
0.31-0.35 ..	1	5	49	67	38	11	3	1	1	—	176
0.36-0.40 ..	—	3	17	35	18	4	1	—	—	—	78
Total ..	4	74	354	385	206	52	16	2	3	1	1097

The Process of Egg Laying.

Pre-ovipositional mandibular operation.

The pre-ovipositional operation of *Nupserha* and the rôle of the mandibles in this connection was not observed by Dutt (1915) or Beeson & Bhatia (1939). The operation consists of two stages: (a) girdling the stem, (b) cutting a slit in between the two rings.

After selecting the site for oviposition, the female, with its head facing downwards, cuts the lower ring first. The insect then makes a complete turn, directing its head upward in order to cut the upper ring. Histological examination of a stem injured by girdling shows that the tissues from the epidermis inwards to the periphery of the pith tissue are pierced by the mandibles, and distinct marks of holes are left in the epidermis (Pl. XVI, figs. 2, 3 & text-fig. 1). The average time taken for cutting the lower ring is 4 min. 26.7 sec. (minimum time—3 min. 35 sec., maximum time—6 min. 15 sec.); 5 min. 33 sec. are required on average (min. time—4 min., max. time—7 min. 30 sec.) for cutting the upper ring.

After the rings have been cut, the female again turns about and faces downward to cut a slit between the two rings at any point nearer the lower one. The slit consists of a central pit and two lateral punctures (Pl. XVI, fig. 4). The central pit and the lateral punctures are apparently made by two successive indentations on the same level as illustrated in fig. 2. It is believed that during the second insertion of the mandibles, one is placed in one corner of one of the punctures already made by the previous insertion. The two inner impressions coalesce so as to form a single central pit. The pit and the lateral punctures penetrate down to the periphery of the pith tissue. That the central pit is the resultant of two mandibular insertions is also supported by the fact that the width of the two lateral punctures together is more or less equal to the width of the central pit (Table II). Neither Trägårdh (1930) nor Duffy (1953), who has recently reviewed the literature on oviposition by means of the ovipositor and the mandibles in the CERAMBYCIDAE, mentions an exactly similar process of cutting the slit. The time required for cutting the slit, on an average, is 1 min. 54.4 sec. (min. time—40 sec., max. time—2 min. 45 sec.).

TABLE II.

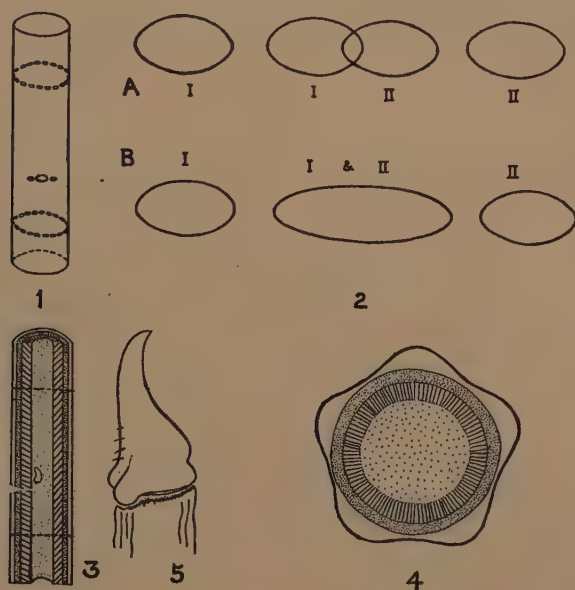
Width of pit and lateral punctures of the slit and the cylindrical capsule of the female genitalia.

	Width in mm. (average of 20)
Slit { left puncture	0.241
right puncture	0.293
pit	0.613
Cylindrical capsule	0.347
Tip of the abdomen (VIII seg.)	0.420

Oviposition.

After the slit has been cut, the insect again turns about and faces upward, and the tip of the abdomen is applied against the pit for oviposition. The cylindrical capsule of the female genitalia is pushed through the pit for deposition of the egg on the inner wall of the woody tissue adjacent to the periphery of the pith slightly above the mouth of the pit (fig. 3). The period of oviposition lasts on an average 2 min. 32.5 sec. (min. time—50 sec., max. time—2 min. 50 sec.).

It is evident from Table II that only the central pit can be used as a passage for oviposition. The width of the central pit is such as to permit the capsule of the genitalia to enter it, while the lateral punctures are too small for this.



Figs. 1-5.—(1) Diagrammatic representation of girdling rings and oviposition slit. (2) Diagrammatic representation showing formation of oviposition slit by two successive indentations of mandibles; A, first (I, I) and second (II, II) insertions; B, lateral punctures (I, II) and the central pit (I & II). (3) Oviposition site. (4) Cross section of apical region of stem showing ridges and furrows. (5) Mandible of adult female.

Factors influencing Choice of Oviposition Site.

Relationship between the site of oviposition and the diameter of the stem.

The position selected for oviposition was further studied, in a sample of 1,000 damaged stems, since it appeared that girdling of the stem and laying of an egg are not done in all regions of the host stem. It was found that they are restricted to that portion of the stem which falls within the diameter range of 0.2 cm. to 0.4 cm. irrespective of plant height (Table III). Observations were, however, restricted to the C.G. variety of *olitorius* jute. Maximum oviposition occurs at that portion of the stem which has a diameter ranging from 0.26 cm. to 0.30 cm. No girdling is ever made or egg laid in the portion of the stem exceeding 0.5 cm. in diameter. In a portion of stem ranging in diameter from 0.41 cm. to 0.5 cm., girdling may be made but no egg is laid. In 99.6 per cent. of all cases of girdling observed it was accompanied by oviposition, while in 0.4 per cent. case rings and slits were cut but no egg was laid. The occurrence of girdling without oviposition was limited to that portion of the stem which fell within the diameter range of 0.41 cm. to 0.5 cm.; thicker parts of the stem were not girdled.

Site of oviposition and susceptibility.

It has already been shown that the loss of stem length is caused by the girdling operation of the female and that the portion of stem selected for oviposition has a diameter ranging between 0.2 cm. and 0.4 cm. Therefore it is the part

of the stem above that which has a diameter range of 0.2 cm. to 0.4 cm. that is susceptible to damage.

Mandibular length and susceptibility of the stem.

An explanation why the rings are cut and oviposition effected at a particular portion of stem which falls within a certain diameter range may be found in the

TABLE III.

Relationship between girdling, diameter of the stem and oviposition.

Stem-diam. classes (cm.)	Frequency of girdling			
	With oviposition		Without oviposition	
	No.	%	No.	%
Up to 0.19	—	Nil	—	Nil
0.2—0.25	218	21.8	—	Nil
0.26—0.30	557	55.7	—	Nil
0.31—0.35	153	15.3	—	Nil
0.36—0.40	68	6.8	—	Nil
0.41—0.45	—	Nil	3	0.3
0.46—0.50	—	Nil	1	0.1
0.51 upward	—	Nil	—	Nil
Total	996	99.6	4	0.4

relationship existing between the length of the mandibles of the female beetle and the depth from the epidermal layer of the host stem down to the periphery of the pith tissue.

In order to determine the relationship between diameter of the stem, depth of stem tissue from the epidermis down to the periphery of the pith (referred to hereafter as the extra-medullary tissue), mandibular length and percentage damage due to oviposition, the observations described below were made, and the data obtained are presented in Table IV. It may be mentioned that there are ridges and furrows on the apical portion of the stem, which is pentagonal in cross section in this region (fig. 4), and therefore the depth of the extra-medullary tissue in the ridge and in the furrow regions will be different. Measurements were therefore taken under the microscope from the ridge and from the centre of the furrow in transverse sections of stem. Pieces of stems falling within six diameter classes were taken for cutting cross sections and taking measurements. One hundred readings for ridges and 100 readings for furrows were taken from 50 different stems falling within each class. The diameter classes were:—below 0.2 cm., 0.2 cm.—0.25 cm., 0.26 cm.—0.30 cm., 0.31 cm.—0.35 cm., 0.36 cm.—0.40 cm., 0.41 cm.—0.45 cm.

The length of the cutting face of the mandibles (fig. 5) of 100 female beetles was measured under the microscope after dissecting them out under the stereomicroscope from materials boiled for about 10 min. in 10 per cent. KOH; its average length was found to be 0.654 mm.

It may be seen from Table IV that maximum girdling (55%) was observed in

stems with diameters ranging from 0.26 cm. to 0.30 cm. The ratio of the mandibular length to the diameter of the stem in this range lies between 1:3.97 and 1:4.58. The thickness of the extra-medullary tissue of this diameter class is 0.525 mm. from the centre of the furrow and 0.651 mm. from the ridge, while the ratio of the mandibular length to this thickness in the furrow is 1:0.80 and 1:0.99 on the ridge. It is also evident from the same Table that the degree of susceptibility to girdling decreases gradually in those regions of the stem where its diameter, and therefore the thickness of the extra-medullary tissue, decreases or increases these ratios.

In thinner parts of the stem, less than 0.2 cm. in diameter, where the ratio of the mandibular length to the diameter of the stem is 1:2.9, no rings are cut. The ratio of the mandibular length to that of the depth of extra-medullary tissue of such a class of stem from furrow and ridge is 1:0.57 and 1:0.70, respectively. In this case the mandibles are too long, and a slit made by the mandibles would cut into the pith and would lead the genitalia to the wrong place for release of the egg. This would account for the fact that portions of the stem of such diameters are rejected. In thicker parts of the stem, with a diameter between 0.41 and 0.45 cm., where the ratio of the mandibular length to the diameter of the stem is between 1:6.26 and 1:6.88, and of the mandibular length to the depth of the extra-medullary tissue in the furrow and on the ridge 1:1.19 and 1:1.37, respectively, there is also no oviposition. In this case the mandibles are too short, and a slit cut by them would not reach the pith and would therefore be unsuitable for oviposition because no part of the female genitalia can actually pierce the tissues to reach the periphery of the pith, where the egg must be deposited. This would account for the absence of oviposition in

TABLE IV.

Mandibular length of female and its ratio to stem diameter and depth of extra-medullary tissue in relation to oviposition.

Stem-diam. classes (cm.)	Mean depth of extra-medullary tissue (mm.) for 100 readings	S.E.	Mean mandibular length for 100 readings	S.E.	Ratio of mandibular length to :		% distribution, within stem-diameter classes, of oviposition sites
					stem-diam. class	depth of extra-medullary tissue	
Up to 0.19	Furrow 0.375 Ridge 0.468	± 0.005 ± 0.006	0.654	± 0.008	1 : 2.90	1 : 0.57 1 : 0.70	Nil
0.20-0.25	Furrow 0.492 Ridge 0.605	± 0.008 ± 0.007			1 : 3.05- 1 : 3.82	1 : 0.75 1 : 0.92	21.79
0.26-0.30	Furrow 0.525 Ridge 0.651	± 0.006 ± 0.006			1 : 3.97- 1 : 4.58	1 : 0.80 1 : 0.99	55.06
0.31-0.35	Furrow 0.571 Ridge 0.701	± 0.007 ± 0.004			1 : 4.74- 1 : 5.35	1 : 0.87 1 : 1.07	16.04
0.36-0.40	Furrow 0.671 Ridge 0.776	± 0.009 ± 0.008			1 : 5.50- 1 : 6.11	1 : 1.02 1 : 1.18	7.11
0.41-0.45	Furrow 0.778 Ridge 0.900	± 0.001 ± 0.001			1 : 6.26- 1 : 6.88	1 : 1.19 1 : 1.37	Nil

regions of the stem with diameters greater than 0.4 cm., though occasional girdling without oviposition occurs (see Table III). Thus the length of the mandibles is the factor that determines what parts of the stem of *olitorius* jute are susceptible to attack.

Stem-diameter range and susceptibility in cases of other hosts.

Oviposition in other host-plants has been found to be limited by the same ratio of mandibular length to depth of the extra-medullary tissue, but the favourable ratio of mandibular length to stem diameter is variable. Thus in some plants, such as a few species of *Sesbania*, and *Aeschynomene aspera*, the pith is very well developed in relation to the extra-medullary tissue, resulting in a stem that, whilst having a suitable depth of extra-medullary tissue, has a larger diameter than that in the susceptible range of the C.G. variety of *olitorius* jute.

Thus the ratio between the mandibular length and the depth of stem from the epidermis to the periphery of the pith determines the range of susceptibility on the host stem.

Summary.

Ovipositing females of *Nupserha bicolor* Thoms. ssp. *postbrunnea* Breun. cause loss of stem length in jute, *Corchorus olitorius*, by girdling the stem above and below a slit in which the egg is laid. The slit is made by two successive indentations of the mandibles. It is composed of a central pit and two lateral punctures. Girdling is restricted to that portion of the stem which falls within the stem-diameter range of 0.2 cm. to 0.4 cm.

A relationship exists between the length of the mandibles of the female, the depth of the stem tissue from the epidermis down to the periphery of the pith (extra-medullary tissue), and girdling and oviposition.

For girdling, the optimum ratio between the mandibular length and the depth of extra-medullary tissue as measured from the epidermal furrow and ridge of the stem (pentagonal in this region) is 1:0.80 and 1:0.99, respectively. Frequency of girdling gradually decreases in those regions of stem where the depth of extra-medullary tissue increases or decreases these ratios.

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References.

- BEESON, C. F. C. & BHATIA, B. M. (1939). On the biology of the Cerambycidae (Coleopt.).—Indian For. Rec., N.S. (Ent.) **5**, no. 1, 235 pp.
- DUFFY, E. A. J. (1953). A monograph of the immature stages of British and imported timber beetles (Cerambycidae).—350 pp. London, Brit. Mus. (Nat. Hist.).
- DUTT, H. L. (1915). The soy bean stem-borer.—Agric. J. Bihar-Oris., **3**, pp. 52-56.
- DUTT, N. (1952). *Nupserha bicolor* Thoms. subsp. *postbrunnea* Breun.: a new pest on jute (*Corchorus olitorius* Linn.).—Nature, Lond., **170**, pp. 287-288.

- DUTT, N. (1954). Diapause in *Nupserha bicolor* Thoms. ssp. *postbrunnea* Breun. and its bearing on infestation and control.—Jute Bull., **17**, pp. 286-287.
- TRÄGÅRDH, I. (1930). Some aspects in the biology of longicorn beetles.—Bull. ent. Res., **21**, pp. 1-8.
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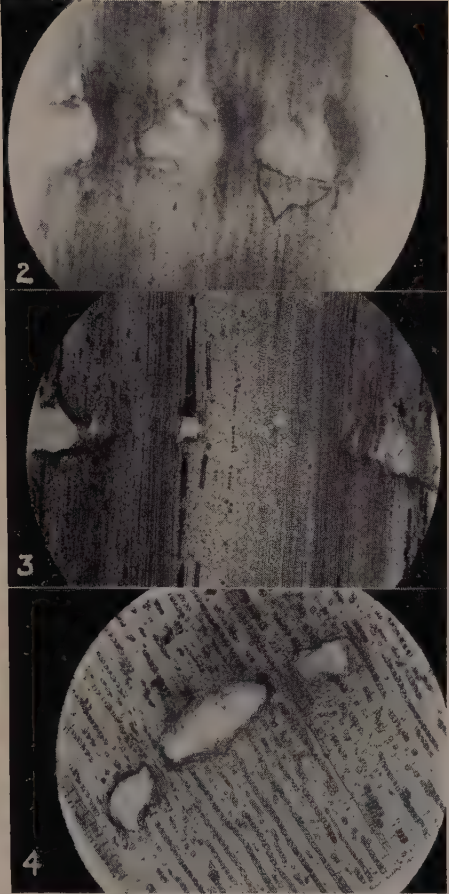


FIG. 1. Withering and drooping apical region above the level of girdling.
FIG. 2. Points of mandibular insertions along the line of girdling.
FIG. 3. Nature of tissue damage by mandibular insertion.
FIG. 4. The central pit and the two lateral punctures of the oviposition slit.

THE MOSQUITOS OF SOUTH THAILAND.

By M. O. T. IYENGAR and M. A. U. MENON

With an Appendix by P. F. MATTINGLY

British Museum (Natural History).

A provisional list of species of mosquitos collected from south Thailand, during an investigation on filariasis carried out under the auspices of the World Health Organisation, was furnished by Iyengar (1953). The collection has now been studied in further detail by the present authors who find that the following corrections require to be made:—

For *Uranotaenia ?micans* Leic. read *Uranotaenia bimaculiala* Leic. For *Aëdomyia venustipes* (Skuse) read *Aëdomyia catastica* Knab. For *Aëdes* (*Aëdes*) *sigmoides* Barraud read *Aëdes* (*Aëdes*) *dux* Dyar & Shann. For *Aëdes* (*Aëdes*) sp. read *Aëdes* (*Aëdes*) *vallistris* Barraud. Add to the list *Anopheles barbum-brosus* Strickl. & Chowd. and *Anopheles letifer* Sandosham.

TAXONOMIC NOTES.

***Uranotaenia bimaculiala* Leicester 1908.**

Several females, one with associated larval skin, were collected at Tharua, Nakhon-Srithamrat Province in January 1952. This species resembles *U. micans* Leic. and *U. edwardsi* Barraud from which it can be recognised by the characters shown in the following Table:—

Characters	<i>U. micans</i> *	<i>U. edwardsi</i> *	<i>U. bimaculiala</i>
Ornamentation on vertex	A V-shaped mark of flat bluish-white scales against a dark background.	No V-shaped mark; vertex mainly covered with flat bluish-white scales.	As in <i>U. micans</i> .
Wing pattern	Basal part of sub-costa pale scaled; basal third of vein 1 pale scaled; vein 6 with a patch of black scales.	Basal part of sub-costa pale scaled; basal third of vein 1 dark scaled, except for a small pale area removed from the base of the vein; vein 6 with white scales on less than basal half, otherwise dark scaled.	Basal part of sub-costa dark scaled; basal third of vein 1 dark scaled, except for a short line of white scales on remigium; vein 6 entirely white scaled (fig. 1, a).
Pale markings on hind tarsal segments 3, 4 and 5	t_3 and t_4 with broad basal bands only; t_5 completely white, except for a patch of dark scales above at tip.	t_3 and t_4 with indistinct pale basal markings; t_5 entirely pale.	t_3 with narrow apical band besides broad basal band; t_4 as well as t_5 entirely white.
Abdomen	Dorsum dark purple brown with apical white bands on some of the basal segments.	Dorsum dark brown with indistinct apical pale markings on tergites III and IV.	Dorsum entirely dark brown or dark purple without any indication of pale banding.

* The characters for *U. micans* and *U. edwardsi* are respectively taken from Bonne-Wepster (1954) and Barraud (1934).

Larva (fig. 1, b-g).

The larva of *Uranotaenia bimaculiala* has not previously been described. The following description is based on the associated fourth-instar skin mentioned above.

Head: Capsule dark brown and strongly chitinised. Antenna short, spiny on outer aspect, with 4 terminal appendages one of which is distinctly flattened and leaf-like, the others being pointed bristles. Neither the antennal hair nor its root

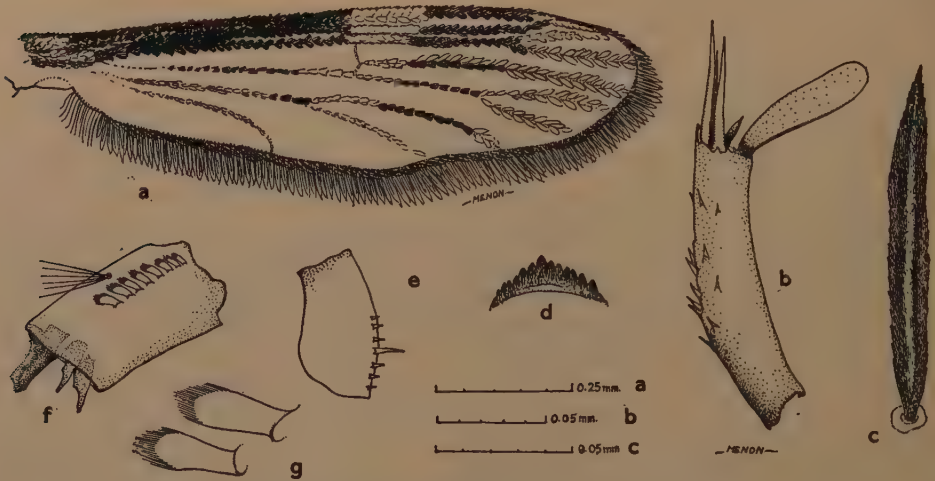


Fig. 1.—*Uranotaenia bimaculiala* (a, adult; b-g, larva).

- a) Wing (magnification $\times 35$).
- b) Antenna (scale b).
- c) Frontal hair *B* (scale b).
- d) Mentum (scale b).
- e) Plate on abdominal segment VIII with comb (scale b).
- f) Siphon (scale a).
- g) Pecten scales (scale c).

could be made out in the specimen; this hair is presumably very minute as in other species of the genus. Frontal hairs *B* and *C* very stout, dark, flattened and leaf-like; *A* missing in specimen, but position clear from root; *B* placed more or less on level with *A*.

Thorax: Prothoracic hairs 1 to 3 arising from common tubercle; hair 1 simple, finely barbed; hair 2 longer, simple; hair 3 short, 4-fid. Hairs 4 to 7 well developed and placed on short tubercles; no. 4 split from base. Hair 8 minute, branched; propleural hairs 9 to 12 weak but tubercle well developed. Mesothoracic hairs 1 to 3 minute; hairs 4 and 5 long, plumose, arising from strong tubercle; hair 6 thin, simple, long; hair 7 split basally into 4 branches, with tubercle; hair 8 small with five frayed branches. Mesopleural hairs 9 to 12 start from a tubercle with two spines; they consist of one long plumose hair, one 5-fid, plumose, fan-shaped hair and two simple hairs. Metathoracic hairs 1 to 5 minute; hair 6 simple, arising from a tubercle; hair 7, 6-branched and fan-shaped; hair 8 minute and 3-branched. Metapleural hairs 9 to 12 on tubercle with two spines, and similar to the mesopleural group.

Abdomen: With prominent lateral hairs on segments I and II, those on other segments inconspicuous. Plates on segment VIII separate; comb of 7 pointed teeth, the middle ones being the largest. Siphon of uniform girth; length 0.35 mm.; siphonal index 1.75; valves exceptionally large; siphonal hair prominent, with 8 branches. Pecten of eight large, very transparent fringed scales (fig. 1, f, g).

Anal segment with denticulate posterior margin; inner submedian caudal hair trifid; outer, missing; fan hairs missing but root of 5 pairs apparent on a rudimentary fan-plate.

Larval habitat.

Fresh-water marsh densely shaded by nipa palms.

***Uranotaenia longirostris* Leicester 1908.**

An adult female of *U. longirostris* was caught while resting on the base of a frond of nipa in a fresh-water marsh near Tharua (Nakhon-Srithamrat Province); two fourth-instar larvae of this species, collected from the water immediately below the spot where the adult was resting, do not differ materially from the description given by Barraud (1934) of the third-instar larva. The important features of the fourth-instar larva are given below.

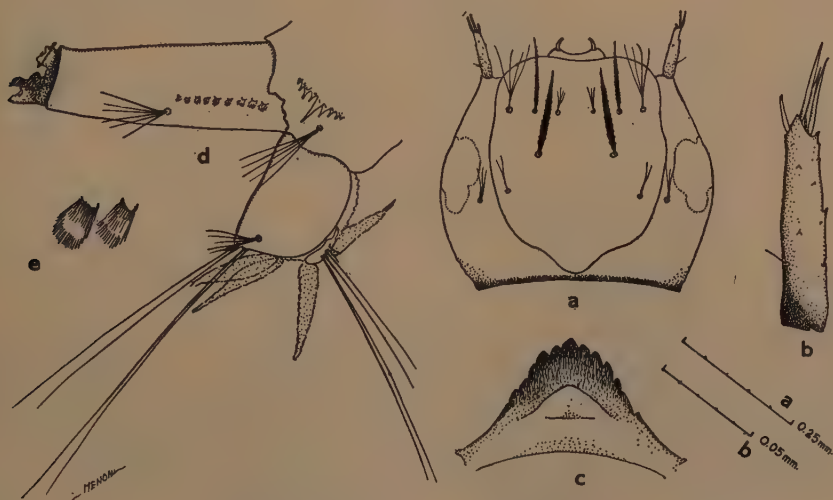


Fig. 2.—*Uranotaenia longirostris* (larva).

- a) Head of larva showing chaetotaxy (scale a).
- b) Antenna (scale b).
- c) Mentum (scale b).
- d) Posterior end of abdomen, showing siphon and anal segment (scale a).
- e) Pecten teeth.

Larva (fig. 2).

Head: Capsule thick and dark; preclypeal spines short, stout, curving inwards. Antenna small, straight, with a tiny hair at about basal third of shaft; tip of antenna with one short and three long appendages. Frontal hairs: *A* moderately conspicuous with about 4 branches; *B* and *C* very stout, flattened, leaf-like and finely barbed; *d* small, trifid; *A*, *B* and *d* in transverse line, *e* posterior and external to *C*; *C* slightly posterior to *B*. Mentum with about 11 rather obtuse teeth, the middle one larger than the rest.

Abdomen: Siphon about 0.45 mm. in length, not including the valves which are comparatively large. Siphonal hair 6 to 7 branched, placed at about middle of siphon; pecten of 8 transparent, fringed teeth. Anal segment about half length of siphon; inner and outer submedian caudal hairs of two branches each; fan-plate absent; fan hairs comparatively few and weak, only two pairs being of any considerable length.

Taeniorhynchus (Coquillettidia) giblini (Taylor) 1914.

The female specimens collected from south Thailand showed the characteristic features noted by Edwards (1922) namely, the dark spots on the posterior half of the scutum, the lateral lobes of scutellum dark and no black ring at tip of hind femur. It was observed, however, that the length of the female palpi was just about one-fourth that of the proboscis, and that the base of the costa and the remigium were covered with purplish scales.

The eggs of this species have not been described so far. The authors studied a cluster of 103 eggs laid in the laboratory by a female. The egg cluster is raft-like. The shape of the raft as well as of the individual egg is similar to that found in *Culex*. There is no micropylar apparatus; the exochorion is mottled. Average dimensions: length 0.85 mm., maximum width 0.25 mm.

Aëdomyia catastica Knab 1909 (fig. 3).

A fourth-instar larva of *Aëdomyia catastica* was collected from a rice-field in Pannarae (Pattani Province) from among a dense growth of *Spirogyra*. The larva

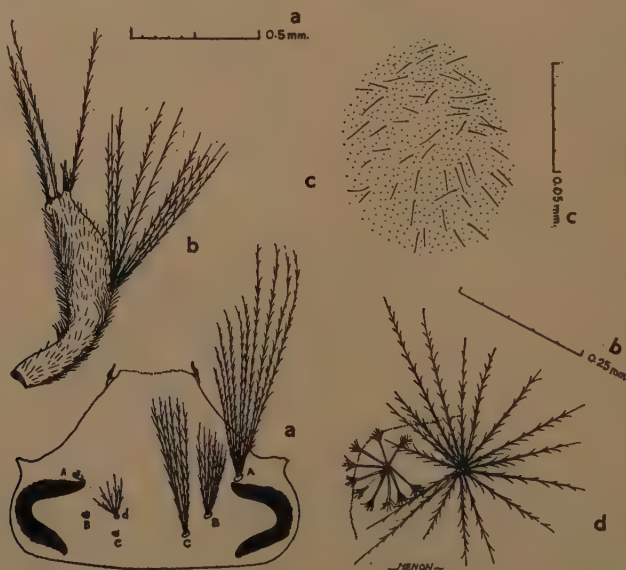


Fig. 3.—*Aëdomyia catastica* (larva).

- a) Head showing arrangement of frontal hairs (scale a).
- b) Antenna (scale a).
- c) Minute hairs on body surface (scale c).
- d) Stellate hairs on abdominal segments (scale b).

was greenish when fresh. It conforms to the descriptions of the species by Mackerras (1937) and Barraud (1934). The following additional features were noted:—

- (i) The frontal plate extends forwards beyond the base of the clypeus as a thin transparent flap overlying nearly the whole of the clypeus.
- (ii) The thorax and abdomen are covered with short downy hairs (average length 10 μ) which are more pronounced on the thorax than on the abdomen.
- (iii) Each of the abdominal segments I to VIII has two pairs of stellate hairs dorsally, the more posterior hair of a segment being the larger. The tips of the branches of the stellate hairs show fraying.

***Aedes (Aedes) dux* Dyar & Shannon 1925.**

(= *Aedes (Aedes) sigmoides* Barraud, 1928 (synonym by Causey, 1937, confirmed by Knight & Hull, 1953).)

A large number of males and females of this species were collected near light at night from several localities in south Thailand. The specimens conform to the descriptions of the species by Laffoon (1946) and Knight & Hull (1953). The configuration of the atrium in the hypopygium of the female (fig. 4, h), differs slightly from the figures given by Barraud (1934).

The following description of our Thailand specimens is intended to supplement the description of the male terminalia of Philippine specimens by Laffoon (1946). Ninth tergite (fig. 4, a) without lobes or setae. Ninth sternite slightly emarginated, with a median patch of setulae. Paraprocts (fig. 4, a) long and sinuous, and

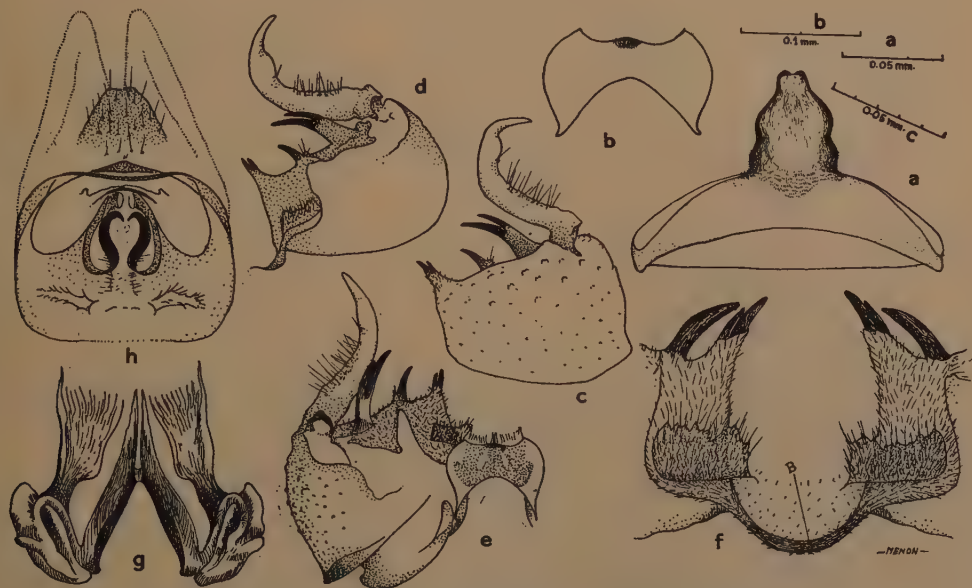


Fig. 4.—*Aedes dux* (a–g, male terminalia; h, female terminalia).

- a) Ninth tergite, paraprocts and tenth tergite (scale b).
- b) Plate overlying phallosome (scale a).
- c) Coxite—sternal aspect (scale b).
- d) Coxite—tergal aspect (scale b).
- e) Terminalia—tergal view (scale b).
- f) Tergal aspect of basal part of coxites showing the basal appendages and the chitinous bridge (B) connecting the coxites (scale c).
- g) Phallosome and parameres (scale c).
- h) Female terminalia (scale b).

connected, except at their tips, by the membranous tenth tergite which is lightly pilose at its proximal end.* Phallosome (fig. 4, g) with lateral plates sharply pointed and slightly serrated. Parameres fimbriated at apex, membranous except along their dorsal edges which are thickened and prolonged posteriorly as small twisted spines. Tergal to the phallosome is a small, bilobed chitinous plate with a postero-median thickening (fig. 4, b). The homologies of this are uncertain.

* The identification of the tenth tergite is in accordance with the views of Barraud (1928) and Laffoon (1946). The present authors, from a study of dissections of the terminalia, are of the view that the structure interpreted as the tenth tergite in *Aedes dux* and *A. butleri* Theo. is the median expansion of the ninth tergite.

Coxites, stumpy and connected medially by a thin curved bridge of chitin. Posterior surface of coxite expansive, almost flat, hairy and armed with a double pointed spine curving inwards; a small conical projection at inner margin of the posterior surface bearing two or three small spines; and half way between occurs a small spine with a hairy, bud-like structure near its base. A transverse flap covered with minute hairs is present on the inner surface, just above the base of the coxite; this probably represents the basal appendage. The style is sickle-shaped and bears a number of hairs along its outer margin at middle.

***Aëdes (Aëdes) butleri* Theobald 1901.**

(= *A. umbrosus* Brug, 1924 (synonym by Knight & Hull, 1953).)

The authors obtained three males and several females of this species from different localities in south Thailand. The females agree generally with the description of *A. butleri* by Barraud (1934) and the males with the description by Laffoon (1946) of *A. umbrosus*, which has been recently synonymised with *A. butleri* by Knight & Hull (1953).

The female terminalia in the Thailand specimens (fig. 5, a) conform to the figure by Barraud (fig. 5, b) except in the structure of the atrium. The figure by Laffoon (fig. 5, c) of the female genitalia of *umbrosus*, however, differs appreciably

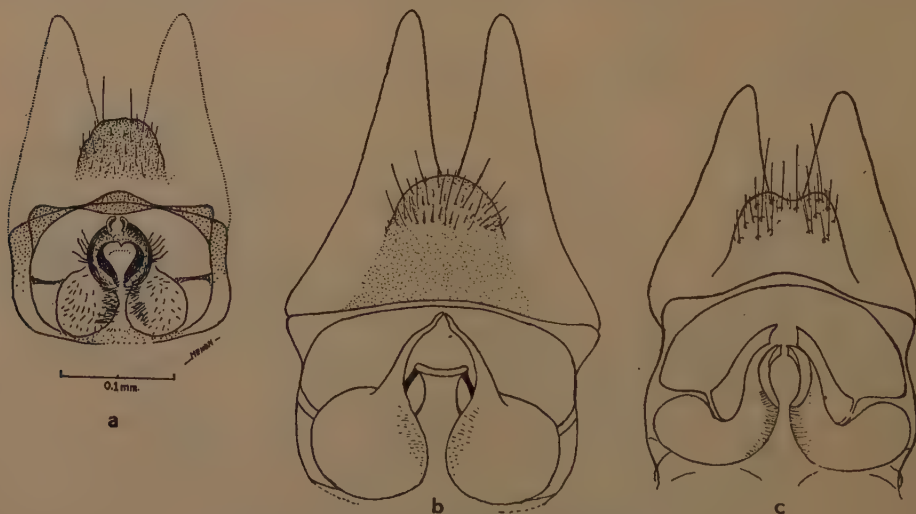


Fig. 5.—*Aëdes butleri* (female terminalia).

- a) Female terminalia in Thailand specimens.
- b) Female terminalia (after Barraud, 1934).
- c) Female terminalia of *A. umbrosus* (after Laffoon, 1946).

in the shape of the post-genital plate and of the postatrial plates. According to the figure by Laffoon, the posterior margin of the post-genital plate is emarginate, whereas in the present series as well as in Barraud's figure, it is rounded. The postatrial plates as shown by Barraud and in the Thailand specimens have a circular contour while Laffoon shows them as transversely elliptical. Mr. Mattingly informs us that in one of the female syntypes of *Aëdes butleri* in the British Museum the tip of the post-genital plate is smoothly rounded while in the other it is emarginate. The latter specimen is almost identical with one of Laffoon's from the Philippines and in Mr. Mattingly's view this variation is without significance. The postatrial plates of Laffoon's specimen show no significant difference from those of our Thailand specimens.

The male terminalia in the Thailand specimens (fig. 6) bear close similarity to those figured by Laffoon (1946). Certain characteristic features of the terminalia observed in these specimens are incorporated in the following re-description of the male terminalia of the species.

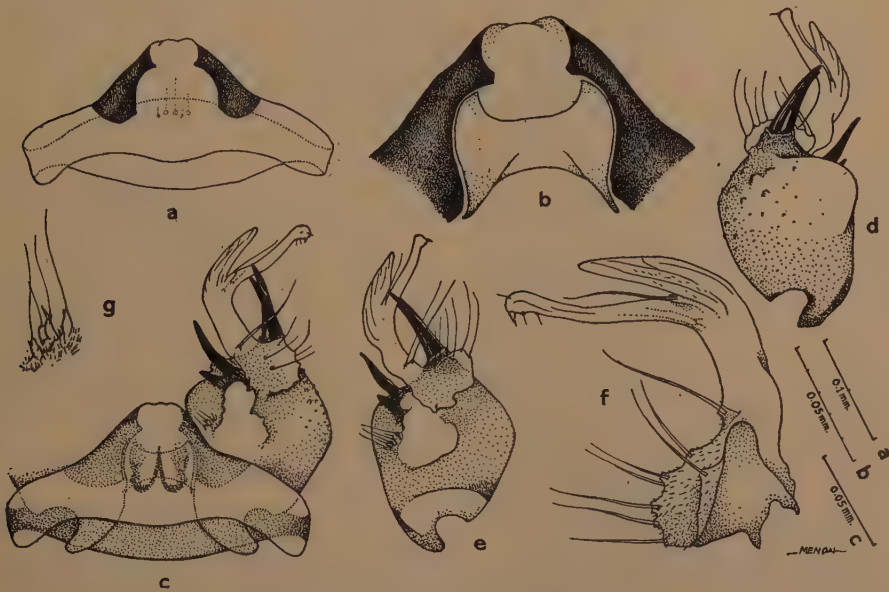


Fig. 6.—*Aedes butleri* (male terminalia).

- a) Ninth and tenth tergites, ninth sternite and paraprocts (scale a).
- b) Paraprocts and plate overlying phallosome—sternal view (scale c).
- c) Male terminalia—tergal view (scale a).
- d) Coxite in sternal view (scale a)
- e) Coxite in tergal view (scale a).
- f) Style (scale c).
- g) Sensory hair-group at base of coxite (scale b).

Ninth tergite without lobes or setae. Ninth sternite convex with a small median patch of setulae. Paraprocts and tenth tergite truncated (fig. 6, a, b).^{*} Phallosome and associated structures similar to those of *Aedes dux* (fig. 6, b, c). Coxite short, bulbous, with apex bearing a pair of dark, strong, subequal spines; another pair of small, subequal spines arising from the inner dorsal aspect. The coxite has no basal appendage as such, but in its position occurs a group of characteristic sensory hairs. Style subterminal, roughly sickle-shaped; the apical part of the style is split up to form an upper blade-like and a lower rod-like arm, with a long hair and one or two small hairs arising at the angle between the two arms; the lower arm carries a short terminal spine and about three small sub-terminal hairs on its slightly expanded apex; the style has a basal expansion carrying several long hairs.

Aedes (*Aedes*) *vallistris* Barraud 1928.

One female specimen of this species was caught while biting in a jungle near Yala, and a male near light at Pattani. The female conforms to the description of the species by Barraud (1934); the male (fig. 7, a–d) differs in just one respect, namely the number of spines at ventral root of coxite. According to Barraud their number is 4 whereas in the specimen from Thailand these spines are decidedly more numerous, as many as 12 or more. Mr. Mattingly informs us that

Barraud's statement is inaccurate; he mentions that the exact number of spines in the terminalia of the type male of *A. vallistris* cannot be counted without remounting but they are clearly more numerous than Barraud says and their number is of the same order as in our Thailand specimen. The paraprocts are

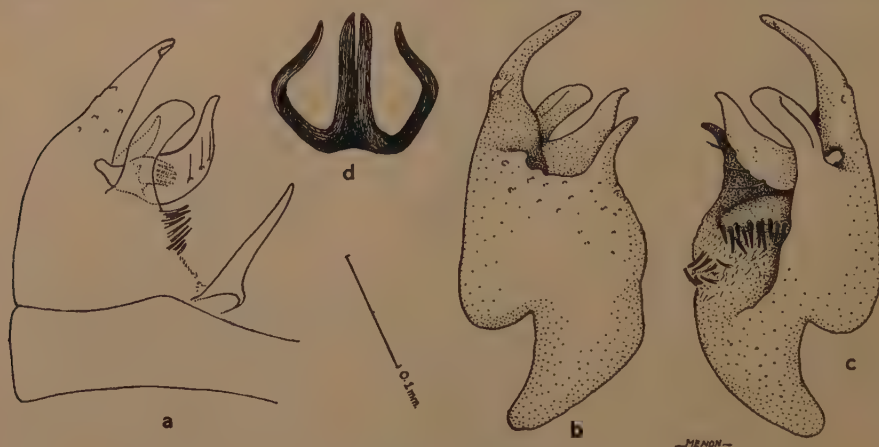


Fig. 7.—*Aedes vallistris* (male).

- a) Tergal view of male hypopygium (right half).
- b) Sternal view of coxite.
- c) Tergal view of coxite.
- d) Phallosome and parameres.

more clearly defined than in the two species of *Aedes* described above and the tenth tergite is less strongly chitinised and very delicate and transparent. The parameres are very strongly sclerotised and the small plate tergal of the phallosome appears less strongly bilobed.

***Anopheles barbumbrosus* Strickland & Chowdhury 1927.**

A single male of the *Anopheles hyrcanus* (Pall.) group of Reid (1950)—which includes *hyrcanus*, *barbirostris* Wulp and allies—collected from Tharuah (Nakhon-Srithamrat Province) has been provisionally determined as *A. barbumbrosus*, as its hypopygium is similar to that described by Christophers (1933) for this species. The phallosomal leaflets showed minute serrations on one side only. It differs from the figure given by Christophers in that the first four phallosomal leaflets are well developed instead of only the first two being well developed (fig. 8).

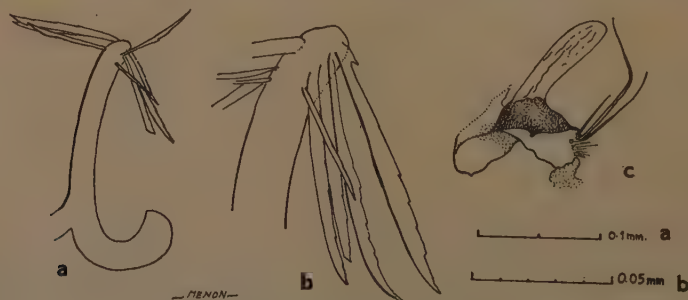


Fig. 8.—*Anopheles barbumbrosus* (parts of male hypopygium).

- a) Phallosome (scale a).
- b) Tip of phallosome showing leaflets (scale b).
- c) Harpago (scale a).

A further difference noticed was the presence of scattered pale scales on the venter of abdomen. According to Christophers (*loc. cit.*), and Bonne-Wepster & Swellengrebel (1953), such pale scales are not present in *barbumbrosus*, and this character has been used by them to differentiate this species from *barbirostris*. Mr. J. A. Reid (personal communication, 1954) to whom this question was referred, has stated that "the presence of white scales on the venter is very characteristic of most members of the *barbirostris* group". The identity of the Thailand specimen needs further study in view of the differences noted.

Summary.

The present list of the mosquitos of south Thailand makes certain corrections to a list previously published and adds *Anopheles barbumbrosus* Strickl. & Chowd. and *Anopheles letifer* Sandosham to the list.

Taxonomic notes are given on eight species and a description of the larva of *Uranotaenia bimaculiala* Leic., previously undescribed, is included. The characters by which *U. bimaculiala* can be separated from the closely allied *U. micans* Leic. and *U. edwardsi* Barraud are detailed.

Acknowledgements.

The authors are greatly indebted to Mr. P. F. Mattingly of the British Museum (Natural History) for helpful criticism of the paper.

References.

- BARRAUD, P. J. (1928). A revision of the Culicine mosquitoes of India. Part XXIV. The Indian species of the subgenera *Skusca* and *Aedes* . . .—Indian J. med. Res., **16**, pp. 357–375.
- BARRAUD, P. J. (1934). The fauna of British India . . . Diptera. Vol. V. Family Culicidae. Tribes Megarhinini and Culicini.—463 pp. London, Taylor & Francis.
- BONNE-WEPSTER, J. (1954). Synopsis of a hundred common non-Anopheline mosquitoes of the Greater and Lesser Sundas, the Moluccas and New Guinea.—Docum. Med. geogr. trop., **6**, pp. 1–29.
- BONNE-WEPSTER, J. & SWELLENGREBEL, N. H. (1953). The Anopheline mosquitoes of the Indo-Australian region.—504 pp. Amsterdam, de Bussy.
- CAUSEY, O. R. (1937). Some Anopheline and Culicine mosquitoes in Siam with remarks on malaria control in Bangkok.—Amer. J. Hyg., **25**, pp. 400–420.
- CHRISTOPHERS, S. R. (1933). The fauna of British India . . . Diptera. Vol. IV. Family Culicidae. Tribe Anophelini.—371 pp. London, Taylor & Francis.
- EDWARDS, F. W. (1922). A synopsis of adult oriental Culicine (including Megarhinine and Sabethine) mosquitoes. Part I.—Indian J. med. Res., **10**, pp. 249–293.
- IYENGAR, M. O. T. (1953). Filariasis in Thailand.—Bull. World Hlth Org., **9**, pp. 731–766.
- KNIGHT, K. L. & HULL, W. B. (1953). The *Aedes* mosquitoes of the Philippine Islands. III. Subgenera *Aedimorphus*, *Banksinella*, *Aedes* and *Cancraëdes* (Diptera, Culicidae).—Pacif. Sci., **7**, pp. 453–481.
- LAFFOON, J. (1946). The Philippine mosquitoes of the genus *Aedes*, subgenus *Aëdes*.—J. Wash. Acad. Sci., **36**, pp. 228–245.
- LEICESTER, G. F. (1908). The Culicidae of Malaya.—Stud. Inst. med. Res. F.M.S., **3**, no. 3, pp. 18–261.

- MACKERRAS, I. M. (1937). Notes on Australian mosquitoes (Diptera, Culicidae). Part III. The genus *Aëdomyia* Theobald.—Proc. Linn. Soc. N.S.W., **62**, pp. 259–262.
- REID, J. A. (1950). The *Anopheles umbrosus* group (Diptera: Culicidae). Part I: Systematics with descriptions of two new species.—Trans. R. ent. Soc. Lond., **101**, pp. 281–318.

APPENDIX.

By P. F. MATTINGLY

British Museum (Natural History).

Several of the species mentioned in this paper are represented in the British Museum by a series of syntypes. It has therefore seemed desirable to choose and mark lectotypes as follows:—

***Uranotaenia micans* Leicester (1908, p. 206).**

The British Museum has 8 syntypes (7 ♀♀ and 1 ♂) from Kuala Lumpur with various dates between 29.ix.1903 and 17.xii.1903 and 2 syntypes (1 ♂ and 1 ♀) without data. I have marked a ♂, dated 4.xii.1903, as holotype and a ♀, with the same date, as allotype. Both are stated on the data labels to have been caught among grasses on swampy ground, Circular Rd., Kuala Lumpur. The series agrees well with Leicester's description except that in all the syntypes there is a long dark patch at or near the base of the first vein so that the basal pale area on this vein is short and corresponds only to the distal portion of the subcostal pale area. In addition to this the dark spot on the sixth vein is absent in some specimens and the extent of pale scaling on the abdomen is variable. In the holotype ♂ none of the tergites has more than a very narrow apical pale band. In the allotype ♀ the first four tergites are very largely pale. Other specimens are intermediate.

***Uranotaenia bimaculiala* Leicester (1908, p. 208).**

The British Museum has 1 ♂ and 5 ♀ syntypes. The male is marked as taken "By water in jungle, Raub, 1/5/04". I have marked it as holotype. The ♀♀ have various data. I have marked as allotype one marked "Jungle patch 4 miles fr. Kuala Lumpur, 14/11/03". The others I have marked as paratypes.

***Aëdes butleri* Theobald (Monogr. Culic., 2, p. 230, 1901).**

The British Museum has 3 ♀ syntypes, 2 dissected and 1 undissected. As noted by Knight & Hull (1953, p. 476), the undissected specimen belongs to a different species. I have marked one of the dissected specimens as holotype. This specimen bears the data "28.10.99, Selangor, A. L. Butler" and also, on the underside of the mount, "Klang Jungle, Sept." and, on a separate label, "K. Selangor (mangroves) swarming". I have marked the other dissected ♀ as a paratype. It bears the data "28.10.99, Selangor, A. L. Butler, Klang, very common & troublesome". Lastly I have marked the undissected ♀ as a paratype and transferred it, in the collection, to subgenus *Skusea*. It has only the data "28.10.99, Selangor, A. L. Butler".

***Aëdes umbrosus* Brug.**

The British Museum has 3 syntypes (2 ♂♂ and 1 ♀). All three specimens bear the data "E. Borneo, Tanalrogot, Dr. S. L. Brug". The locality is misspelt

and should read "Tanah Grogot". One of the ♂♂ is dissected and the other not. I have marked the dissected specimen as holotype and the other as a paratype. I have marked the ♀ specimen as allotype.

Aedes sp. ? No. 50 Borel (Les Moustiques de la Cochinchine et du Sud-Annam, p. 287, 1930).

It would appear that this is *Aedes dux* Dyar & Shann. The synonymy has not been published before.

THE PERSISTENCE AND TOXICITY OF INSECTICIDES UNDER TROPICAL CONDITIONS.

I.—THE PERSISTENCE OF γ BHC AND ITS TOXICITY TO *TRIBOLIUM CASTANEUM* (HBST.).

By J. C. DUERDEN, L. A. W. HAYWARD and B. SOMADE
West African Stored Products Research Unit, Lagos, Nigeria.

Many thousands of tons of bagged, decorticated groundnuts are stored for periods of up to 15 months in warehouses in Kano, Northern Nigeria. A large indigenous population of *Tribolium castaneum* (Hbst.) infests the stored nuts and considerable losses are caused. In 1948, investigations into the control of this and other pests by means of insecticides were commenced. As a result of these trials (Howe, Hayward & Cotterell, 1952) a routine programme of control measures was evolved, based upon the application of γ BHC as a water-dispersible powder at monthly intervals. Subsequent observations indicated that large numbers of *T. castaneum* were present within two weeks after spraying and preliminary experiments suggested that the probable cause was the inadequate persistence of BHC under the climatic conditions prevalent in Northern Nigeria.

Recent intensification of the control measures necessitated a more accurate knowledge of the persistence and toxicity of γ BHC at different rates of application under conditions in Kano.

Experimental Techniques.

General methods.

In the preliminary trials, circular discs of sacking were pinned to the surfaces of stacks of bagged groundnuts in a warehouse. A 25 per cent. water-dispersible lindane formulation was applied uniformly over the stack by means of a pressure-retaining knapsack-type sprayer. Despite careful application under still conditions the deposits obtained varied from 20 to 47 mg. γ BHC per sq. ft.

An attempt was then made on a laboratory scale to obtain more uniform deposits by means of a small hand atomiser of the scent-spray type operated by depressing a small plunger. A constant volume of a suspension of 50 per cent. lindane dispersible powder in water was applied to filter papers, but the rate of settling of the suspension resulted in widely varying initial deposits.

Eventually it was found that consistent initial deposits could be obtained on filter papers by applying the γ BHC in a volatile organic solvent by means of the hand atomiser. This was designed to deliver a constant volume, the rate of application being controlled by varying the strength of the solution. Even using this technique only a proportion of the actual volume delivered was obtained as a recoverable deposit on the filter papers. With carefully controlled conditions, however, this proportion was sufficiently constant to enable up to a hundred papers to be treated with little variation of initial deposit using the same dosage rate. This may be termed the spraying factor for the particular set of conditions and the accurate knowledge of this factor enabled the following technique to be adopted in all the experiments.

A specimen of lindane of melting-point range 109.5–113°C. was prepared by recrystallisation in petroleum ether solution from a 50 per cent. formulation. Initial deposits of approximately 10, 20 and 40 mg. of lindane per sq. ft. were

required and solutions of the recrystallised lindane in 60–80°C. petroleum ether of the appropriate strengths were prepared. These were applied by means of the hand atomiser as evenly as possible to Whatman No. 4 (15 cm.) filter papers.

Sufficient papers were treated at each rate of application to allow replicated chemical and biological assessments to be carried out on eight different occasions. The first assessments were made on one series of papers, taken at random, immediately spraying was completed and the petroleum ether had evaporated. The rest were pinned, with sprayed side uppermost, on plaster boards and placed in a typical Kano store for the duration of the experiment. A similar set of untreated papers was also prepared and placed in the store. Thereafter sampling at random was carried out at two-day intervals up to the tenth day after treatment, then on the fifteenth day and final samples taken 20 days after the initial application.

Biological assessments.

The determinations of toxicity were made using active adults of *T. castaneum* taken at random from flourishing laboratory cultures. Ten insects were enclosed on each filter paper under test in the laboratory by means of a glass cylinder open at both ends.

The number of dead insects was counted every 24 hours on the four successive days after sampling, following which the observations were discontinued. An insect was taken as dead if, even when turned on to its back, it showed no discernible movement. Throughout the biological assessments the mortalities of different replicates of the same sample were reasonably consistent.

Chemical analysis.

BHC was recovered from the filter papers by soxhlet extraction with Petroleum ether "Analar" of boiling point 60–80°C. The solvent was removed to within 2–3 ml. and the BHC was then hydrolysed with monoethanolamine using the method of Howard (1947). The final determination was then carried out on a semi-micro scale using Volhard's method.

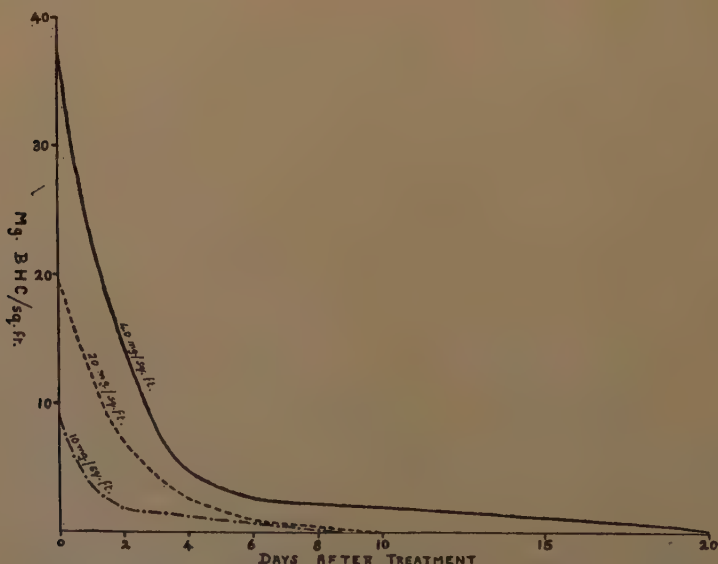


Fig. 1.—Comparative persistence of three rates of application of γ BHC.

Results.

The mean recoveries of BHC expressed as mg. per sq. ft. are presented in fig. 1. In all the chemical determinations different replicates on the same date were reasonably consistent.

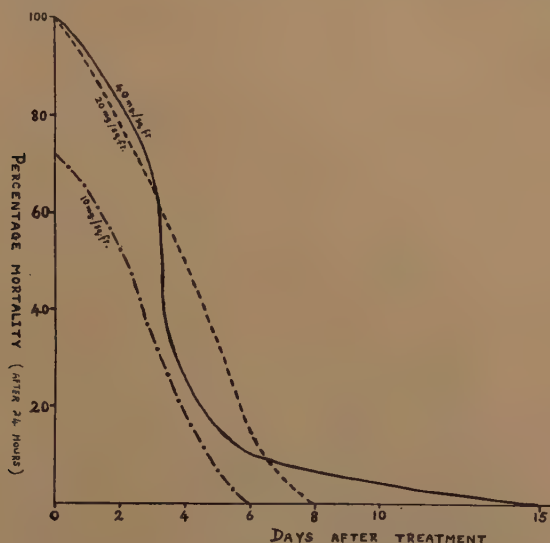


Fig. 2.—Mortality of *T. castaneum* after 24 hours' exposure to γ BHC.

The mean percentage mortalities of *T. castaneum* on each of the four days after sampling are shown in figs. 2, 3, 4 and 5. Again mortalities in different replicates on the same date were reasonably consistent. Occasionally a small number of insects placed on untreated papers died, but only in single replicates on a small number of sampling dates. During the period of the tests the highest

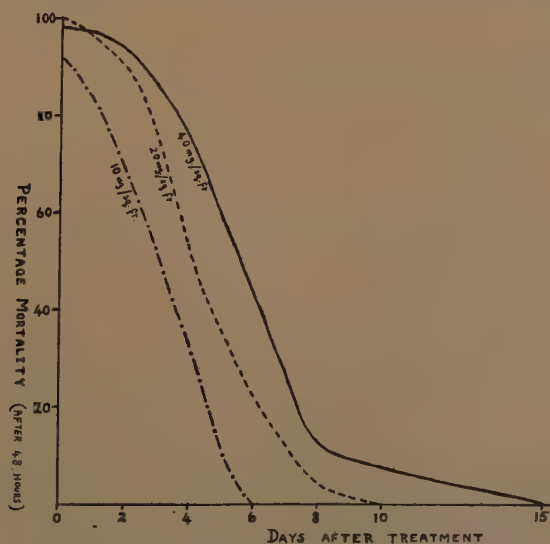


Fig. 3.—Mortality of *T. castaneum* after 48 hours' exposure to γ BHC.

maximum shade temperature recorded was 104°F. and the lowest minimum was 51°F.

Inside the warehouse, however, temperature changes would probably be of less magnitude and would average about 75–80°F.

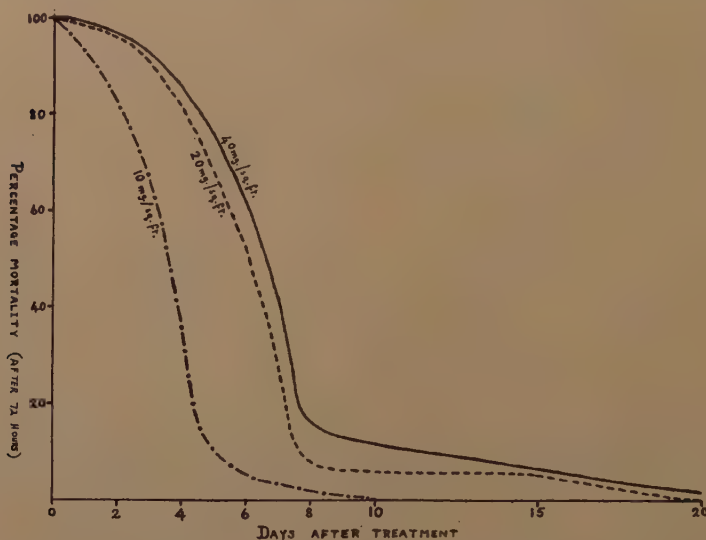


Fig. 4.—Mortality of *T. castaneum* after 72 hours' exposure to γ BHC.

Discussion and Conclusions.

From fig. 1 it may be seen that whatever the initial deposit of BHC it is rapidly reduced on exposure, only the highest rate showing appreciable quantities remaining after one week. Whether the same would be true for deposits on the surfaces of sacks is not known but it is unlikely to be very different.

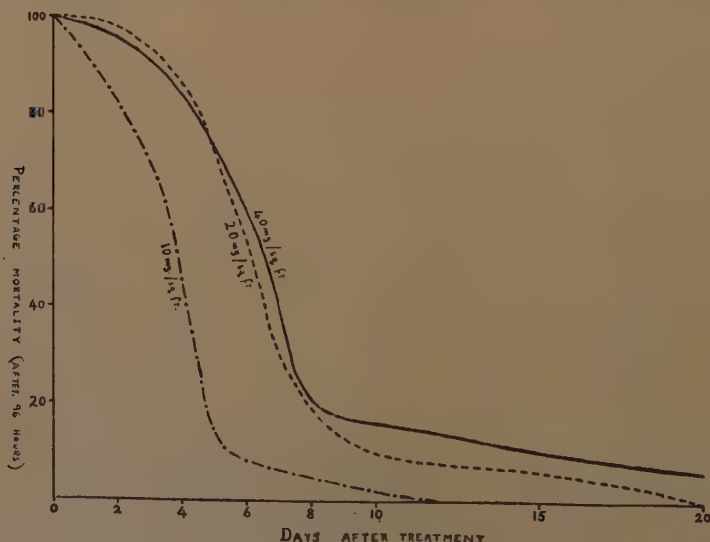


Fig. 5.—Mortality of *T. castaneum* after 96 hours' exposure to γ BHC.

Probably the mortality after 24 hours' exposure (fig. 2) represents conditions nearest to those actually obtaining in the field as it is unlikely that active beetles would remain on a lethal surface for as long as 96 hours. On this basis an initial deposit approximating to 10 mg. per sq. ft. was inadequate for practical control whereas deposits of 20 and 40 mg. gave 100 per cent. mortalities immediately after treatment. Thereafter the mortalities produced by the two higher rates remained very similar for a week, by which time the level of control was inadequate for practical conditions.

As may be expected, an increased kill was obtained with longer exposure of the insects to the treated surfaces. From fig. 5 it may be seen that roughly half the test insects died following 96 hours' exposure to a residual deposit of about 1 mg. per sq. ft., this being the amount left 4 or 6 days after applying a deposit at 10 or 20 mg. per sq. ft., respectively (see fig. 1). However, for purposes of field control, a residue of less than 4 mg. of γ BHC per sq. ft. is probably of little value. With initial deposits of 10, 20 and 40 mg. per sq. ft. this limit was reached after approximately 1, 3 and 4 days, respectively. It is interesting to note that with 96 hours' exposure, residues of less than 0.5 mg. per sq. ft. produced appreciable mortalities.

From the results obtained several important factors emerge. Firstly, from the point of view of the practical control of *T. castaneum* using BHC, an initial deposit greater than 10 mg. per sq. ft. must be applied. Secondly, a deposit of 40 mg. does not show twice the activity of a deposit of 20 mg., and thirdly, the useful life of such a deposit is in the region of four days.

Thus it may be concluded that the most suitable method of maintaining a lethal barrier of BHC to *T. castaneum* under conditions in Kano would be approximately weekly applications of the insecticide at a rate of 20 mg. per sq. ft.

Summary.

The persistence and toxicity to *Tribolium castaneum* (Hbst.) of initial deposits approximating to 10, 20 and 40 mg. per sq. ft. of γ BHC were studied over a period of three weeks in a typical warehouse in Kano, Northern Nigeria. Chemical and biological assessments indicated that the lowest rate of application was inadequate for practical insect control whilst the other two rates showed very similar biological activity up to eight days after treatment. Thereafter small quantities persisted from applications at the highest rate for a further week but the resultant mortalities were inadequate for purposes of field control. It was concluded that to maintain control of *T. castaneum*, weekly applications of BHC would be required and that the rate of application should approximate to 20 mg. per sq. ft.

Acknowledgement.

The 50 per cent. lindane formulation was kindly supplied by Messrs. Imperial Chemical Industries Limited.

References.

- HOWARD, B. H. (1947). Analyst, Lond., **72**, pp. 427-431.
HOWE, R. W., HAYWARD, L. A. W. & COTTERELL, G. S. (1952). Bull. ent. Res., **43**, pp. 259-279.
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SOIL POPULATION STUDIES.

I.—THE EFFECTS OF CULTIVATION AND TREATMENT
WITH INSECTICIDES.

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This contribution to soil ecology is concerned with the influence of cultural operations and with the effects of the persistent synthetic insecticides DDT and BHC on the soil micro-arthropoda of old grassland at Glasgow; the original population will be described in detail elsewhere.

Undesirable changes in the composition of animal communities after treatment with chemicals are now well-known phenomena and, in recent years, with the introduction and widespread use of persistent chlorinated hydrocarbons in crop protection, reports of resurgences of infestations of various species, particularly Tetranychid mites, have become increasingly common. In most cases, the repercussions have been explained in terms of predator-prey and parasite-host interactions (*e.g.*, Lord, 1949, 1949-50; DeBach & Bartlett, 1951). Although the work of Hueck & others (1952) and Davis (1953) suggests that other factors may be contributory, there is abundant evidence to support the above view because with the reduction of predator and parasite pressure, prey- and host-populations are able to exceed their normal level. While the economic significance of such population changes is self evident, their occurrence also draws attention to the potential value of insecticide treatments as field experimental techniques for fundamental studies of the inter-relationships of animals in arthropod communities. Thus, by disrupting what has been called the quasi-equilibrium of the population (Lotka, 1925), some information might be obtained about the factors responsible for maintaining this alleged state of fluctuating balance. Accordingly, it appeared that insecticides might be used to advantage in a synecological study of the soil mesofauna. Moreover, it also seemed particularly desirable to acquire some information on the effects of such widely used materials as DDT and BHC on a population which probably plays an important rôle in the processes of organic decay and in the release of plant nutrients.

In its original conception the investigation did not include observations on the effects of cultivation. However, after preliminary trials with various formulations of the two insecticides it became evident that surface applications on grassland would not penetrate the soil in sufficient quantities to induce a statistically significant response in the underlying population. Bearing in mind the original purpose of the treatments, and the need to reduce variation to a minimum, it was necessary to ensure that the insecticides came into contact with the animals. The only practical way of achieving this was to incorporate the chemicals with the soil by cultivation. Hence, the effects of cultivation had to be assessed separately, and finally, the investigation was extended to include observations on the effects of fallowing.

When the study was initiated, no detailed accounts of the effects of insecticides on soil micro-arthropoda had been published. During the course of the investigation, however, accounts of a number of investigations in continental Europe appeared. In Germany, Keller (1951) and von Baudissin (1952) observed

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that "Multanin 50", a proprietary preparation containing DDT and BHC, had an initial destructive effect on Collembola and Acarina. Keller reported that recolonisation by Collembola was rapid, and the rate varied indirectly with the horizontal distance from the edge of the treated area. At a point 6 m. distant from the edge of the plot it was complete in 23 days. Baudissin observed that the initial toxic effect lasted for about 14 days, and thereafter noted an increase in the micro-arthropod population of the treated soil. This he attributed to a chemotactic stimulation by residual quantities of DDT. In Russia, Grigor'eva (1952) found that while phytophagous and predacious species in soil were very susceptible to BHC, saprophagous species increased under the influence of low concentrations and were only adversely affected by high dosages. Finally, Richter (1953) in a study of forest habitats, found that although the ground vegetation was sparse, surface applications of BHC dusts had little effect, but surface treatments with emulsion and suspension formulations of this insecticide caused reductions of mites and Collembola which remained apparent for at least four months. When BHC dusts were thoroughly incorporated with the soil by cultivation, severe reductions of all forms were noted, and this effect persisted for at least ten months. When BHC dust was roughly dug in and not thoroughly mixed with the soil, it appeared to have a stimulating effect and caused an increase of Collembola and Oribatei. DDT was reported to have an adverse effect on Collembola and Acarina, both when applied to the surface as an emulsion, and when hoed into the soil as a dust.

Methods.

Most of the data were obtained by examining soil samples taken periodically from the plots of a randomised-block field experiment in which there were four replications of the following six treatments:—

- (a) Uncultivated; representing the original condition of the area;
- (b) Control; cultivated, and re-seeded with perennial ryegrass (*Lolium perenne*);
- (c) Fallow; cultivated, and kept free of vegetation;
- (d) DDT; cultivated, and soil treated with 2 oz. per sq. yd. of 2 per cent. crude DDT dust (75–80 per cent. p,p'-isomer), then re-seeded;
- (e) BHC; cultivated, and soil treated with 2 oz. per sq. yd. of 2 per cent. crude BHC dust (13 per cent. γ isomer), then re-seeded;
- (f) DDT plus BHC; cultivated, and soil treated with 2 oz. per sq. yd. of 2 per cent. crude DDT, and 2 oz. per sq. yd. of 2 per cent. crude BHC, then re-seeded.

Each plot was 6 ft. square, and was separated within the blocks from its immediate neighbours by an uncultivated interval of 12 ft., the blocks themselves being 13½ ft. apart. The cultivated plots were dug over roughly in early January 1951 and then left to weather until late April when cultivation was continued until a fine tilth was obtained. The insecticides, previously mixed with washed sand to facilitate even distribution, were applied on 17th May 1951 and thoroughly mixed with the soil to a depth of 9 in. The plots were then sown, lightly raked, and rolled with a heavy roller. The operations were so arranged that all the plots concerned received, approximately, an equal amount of cultivation on each occasion, so that variation due to the influence of time of cultivation was minimised. The area was mown when necessary, and the fallow plots kept bare by periodic hoeing.

With an implement removing a core 2 in. in diameter, two random samples per plot were taken on each of the following dates:—9th June, 16th October and 14th December 1951; 20th February, 18th April and 17th October 1952. In June 1951 the samples were taken to a depth of 9 in. and subdivided to represent two strata, 0–3 and 3–9 in. in depth. However, owing to the time taken up by

processing the samples, it was found necessary to curtail the programme, so that on subsequent occasions, although two samples were taken from each plot, they were taken to a depth of 6 in. and were undivided. Although the cores were extracted separately, the statistical analysis, so far as the insecticide and cultivation treatments were concerned, were carried out on the total values of the two samples. The within-plot variation was examined only in the uncultivated plots, and the results of that examination will be published elsewhere. The animals were extracted with a flotation apparatus similar to that described by Salt & Hollick (1944), the smallest component sieve having a regular square mesh of 0.152 mm. (100 mesh B.S.S.).

The field data were supplemented by laboratory observations on the feeding habits of the dominant species, and by toxicity tests designed to provide a broad assessment of the relative susceptibility of the major groups to the materials employed: for this purpose the animals were confined on filter paper substrata treated with known quantities of the insecticides, the deposits being obtained by evaporating standard acetone solutions of p,p'DDT and 99 per cent. γ BHC (*vide* Martin & Wain, 1945).

Analysis of Data.

Owing to the disparity in size, the June samples were considered separately, and, in order to include an assessment of the influence of depth, the comparisons were based on the number of animals per unit volume of soil. The data from the

TABLE I.

Comparisons of populations in the upper 9 in. of soil, June 1951.
Control Populations—100.0.

Group or Species	Undug	Fallow	DDT	BHC	DDT + BHC
Total Collembola	199.2	40.8	155.4	35.4	46.1
Total euedaphic Collembola ..	192.7	41.8	167.3	35.4	49.1
Total Tullbergiinae	245.7	57.1	391.4	28.6	54.3
<i>Tullbergia krausbaueri</i>	280.9	95.2	61.9	33.3	42.9
<i>Tullbergia crassiuscuspis</i>	178.6	0	885.7	21.4	71.4
Total <i>Onychiurus</i> spp.	310.0	80.0	160.0	70.0	65.0
<i>Isotomodes productus</i>	78.7	19.1	23.4	23.4	44.7
<i>Folsomia candida</i>	237.5	12.5	50.0	50.0	12.5
Total hemiedaphic Collembola ..	231.2	43.7	100.0	31.2	31.2
Total Oribatei	160.2	114.1	51.9	92.2	74.3
<i>Punctoribates punctum</i>	101.5	96.2	48.1	90.1	71.8
<i>Minunthozetes semirufus</i>	277.3	150.0	68.2	86.4	90.9
Total <i>Oribella</i> spp.	225.0	150.0	62.5	150.0	100.0
Total immature Oribatei	425.0	25.0	50.0	75.0	25.0
Total Acaridiae	620.0	100.0	140.0	200.0	220.0
<i>Rhizoglyphus echinopus</i>	933.3	66.7	200.0	166.7	200.0
Total other Acaridiae ⁽¹⁾	150.0	150.0	50.0	250.0	250.0
Total Mesostigmata	200.0	51.7	78.3	63.3	33.3
Total Rhodacaridae	158.3	38.9	88.9	66.7	36.1
<i>Rhodacarellus epigynialis</i>	148.4	29.0	87.1	48.4	35.5
Total known predacious					
<i>Mesostigmata</i> ⁽²⁾	283.3	116.7	50.0	66.7	50.0
Total <i>Pergamasus</i> spp.	266.7	100.0	100.0	100.0	0
Total immature <i>Mesostigmata</i> ..	185.7	57.1	71.4	64.3	14.3

(1) Total of 3 species:—*Acarus siro* L., *Tyrophagus castellanii* (Hirst) and *Glycyphagus destructor* (Schränk).

(2) Total of 5 species:—*Pergamasus runciger* Berl., *P. misellus* Berl., *Veigaia nemorensis* (Koch), *Digamasellus* sp., and *Hypoaspis aculeifer* (Can.).

6-in. samples taken during the period October 1951–October 1952 were first subjected to an analysis of variance over all five occasions, further examination being undertaken in the case of groups and species showing significant interactions of treatments with time. In respect of both the June 1951 and October 1951–October 1952 comparisons, the plot totals for analysis were derived from the square-root transformed sample data, and degrees of freedom were apportioned as follows:—

June 1951		October 1951–October 1952	
Item	D.F.	Item	D.F.
Treatments	5	Treatments	5
Depth	1	Time of sampling	4
Blocks	3	Blocks	3
Treats. \times blocks	15	Treats. \times blocks	15
Treats. \times depth	5	Treats. \times time	20
Depth \times blocks	3	Time \times blocks	12
2nd order interaction	15	2nd order interaction	60
Total	47	Total	119

Field Results.

Early effects, June 1951.

A comparison of populations on 9th June 1951 (23 days after treatment with insecticides) is given in Table I, while Table II summarises the results of statistical analyses of population densities. The main trend of the results at this time consisted of drastic reductions due to cultivation and re-seeding alone (the control treatment), while in a number of cases further smaller reductions were apparent in the fallow and insecticide-treated plots. A number of Collembolan groups and species, however, were observed to attain higher population levels in the DDT-treated plots. Statistically significant differences were generally confined to comparisons of the "uncultivated" population with those of the other treatments in the experiment, although there were certain exceptions. Thus, the DDT plus BHC-treated population of *Mesostigmata* (total) was significantly lower than the control and that treated with DDT alone.

In a number of analyses, significant values of the variance ratio, *F*, were obtained for the interaction of treatments with depth. In most of the groups and species concerned this could be attributed to the paucity or virtual absence of animals in the lower strata of all plots, but in the dominant *Oribatei* there was an indication of a more even vertical distribution in the cultivated soil. The populations of *Punctoribates punctum* (Koch) in the lower strata of all the cultivated plots, with the exception of those treated with DDT, were significantly higher than the lower stratum population of this species in the uncultivated soil.

Subsequent trends, October 1951–October 1952.

(a) *Main effects.*—The average effects of the treatments over this period are depicted diagrammatically in figs. 1–3, the histograms being proportional to the untransformed treatment totals. These diagrams can be examined in conjunction with Table III, where the results of statistical analysis of the square-root transformed data are summarised.

As shown in the comparison of the uncultivated and control populations, cultivation and re-seeding resulted, in almost all species and groups of soil microarthropoda, in a reduction of the population. In most of the Collembola, and particularly in the truly subterranean or euedaphic groups and species, the control was observed to be considerably lower than the uncultivated population, but in no case was this difference statistically significant. Two Collembolan species were observed to increase (non-significantly) as a result of re-seeding, and in the case of the near-surface dwelling (hemiedaphic) forms the observed overall

difference was small. In the mites, all the Oribatei were severely and significantly reduced in numbers by re-seeding, as also was the population of *Rhizoglyphus echinopus* (Fum. & Rob.). All the Mesostigmata analysed were significantly less abundant in the control, but, taking the group as a whole, the reduction was not so severe as in the Oribatei. Fallowing was seen to result in a marked reduction of all forms. In most of the Collembola, and in the RHODACARIDAE (Mesostigmata), the fallow population was significantly lower than the control, but in Oribatei there were no significant fallow/control comparisons.

TABLE II.

Results of analysis of data of 9th June 1951, based on square-root transformations of the original figures.

Group or species	(i) Undug	(ii) Fallow	(iii) Control	(iv) DDT	(v) BHC	(vi) DDT + BHC	(vii) F (treat- ments)	(viii) S.E.	(ix) F (treat- ment \times depth)
Total Collembola	52.6	21.1	34.4	35.6	20.1	24.1	3.60	6.5	1.93
Total euedaphic Collembola	50.6	19.1	30.6	32.4	17.4	21.6	3.44	6.7	—
Total Tullbergiinae ..	28.7	10.5	14.7	23.0	6.1	10.3	2.09	—	1.74
<i>Tullbergia krausbaueri</i> ..	22.9	10.5	11.8	8.2	4.4	6.1	3.97	3.3	1.25
<i>Tullbergia crassiuspis</i> ..	10.5	0	6.2	18.8	1.7	4.6	1.67	—	1.68
Total <i>Onychiurus</i> spp. ..	19.5	8.6	8.2	11.6	7.6	6.7	2.60	—	—
<i>Isotomodes productus</i> ..	13.2	3.7	13.6	7.3	5.7	9.5	1.02	—	1.59
<i>Folsomia candida</i> ..	7.4	0.7	4.9	2.0	2.4	1.0	1.35	—	—
Total hemiedaphic Collembola	17.8	5.0	9.3	9.7	3.4	3.1	4.78	2.5	4.53
Total Oribatei	53.6	47.8	45.0	29.4	40.6	36.8	1.38	—	6.93
<i>Punctoribates punctum</i> ..	32.3	32.9	33.4	21.5	31.8	26.9	—	—	5.39
<i>Minunthozetes semirufus</i> ..	30.1	22.5	17.9	13.0	14.9	17.0	1.91	—	4.54
Total <i>Oribella</i> spp. ..	11.6	7.5	6.1	3.8	6.8	3.5	2.09	—	7.76
Total immature Oribatei ..	8.2	1.0	2.7	1.0	1.7	1.0	2.18	—	3.84
Total Acaridiae	14.7	4.1	3.4	4.9	5.8	7.7	2.36	—	1.41
<i>Rhizoglyphus echinopus</i> ..	12.8	1.7	2.4	4.4	3.1	4.5	2.06	—	1.75
Total other Acaridiae ..	2.7	2.4	2.0	1.0	2.6	3.1	—	—	—
Total Mesostigmata ..	36.2	14.6	23.0	19.1	16.9	10.1	13.10	2.5	3.49
Total Rhodacaridae ..	22.3	6.9	15.5	13.2	13.3	7.1	5.44	2.4	—
<i>Rhodacarellus epigynialis</i> ..	18.0	4.6	12.2	10.8	9.0	6.5	2.26	—	—
Total known predacious Mesostigmata	12.1	5.2	3.8	2.0	2.7	1.7	9.00	1.1	3.99
Total <i>Pergamasus</i> spp. ..	6.1	2.4	2.1	2.0	1.7	0	1.67	—	4.23
Total immature Mesostigmata	14.4	5.8	9.1	6.4	5.3	1.4	3.95	2.2	8.99

Columns (i-vi): Treatment totals.

Col. (vii): Values of variance ratio, F , for treatment comparisons (degrees of freedom, $n_1 = 5$, $n_2 = 15$). Significance levels:— $P = 0.05$, 2.90; $P = 0.01$, 4.56.

Col. (viii): S.E. of treatment totals. Values of $\sqrt{2t}$ for 15 d.f.:— $P = 0.05$, 3.0; $P = 0.01$, 4.2.

Col. (ix): Values of F for interaction of treatment with depth. D.f., $n_1 = 5$, $n_2 = 15$. Significance levels as for col. (vii).

With regard to the insecticide treatments, severe reductions of Collembola and Acarina were observed in the plots treated with BHC. Significant BHC/control comparisons were frequent in the Collembola and in the Mesostigmata, but amongst the Oribatei the overall reduction attributable to BHC was significant

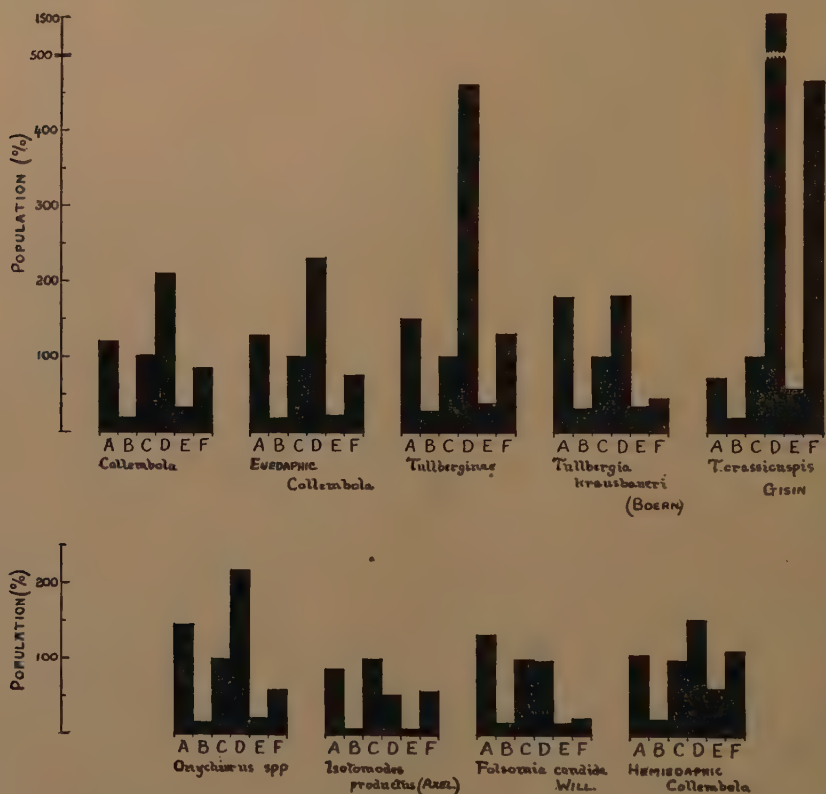


Fig. 1.—Overall effects of treatments, October 1951–October 1952. Collembola. A, undug; B, fallow; C, control; D, DDT; E, BHC; F, DDT + BHC.

only in *Minunthozetes semirufus* (Koch). With only two exceptions, treatment with DDT caused a marked reduction of Acarina. Again this reduction was not significant in the Oribatei, but significant DDT/control comparisons were evident in the analyses of total Mesostigmata, total immature Mesostigmata and in the total population of the five species of Mesostigmata observed to be predacious. In Collembola, however, the DDT population was very much higher than the control, and there were only two exceptions to this. Taking Collembola as a whole, the DDT-treated population was 110 per cent. higher than the control, the significance of this difference being in the 0.01–0.001 probability range. In this comparison a high order of significance was also established in a number of the constituent groups and species.

For most of the Collembola, the destructive influence of the mixed insecticides was considerably less than that of BHC alone. In the analyses of total Collembola and total euedaphic Collembola, the populations of the plots receiving both insecticides, while being significantly lower than those treated with DDT,

were significantly higher than the populations treated with BHC alone. In the Oribatei, the populations receiving the mixed insecticides were in all cases lower than the controls, but this difference was significant only in the case of *M. semirufus*. When compared with the populations receiving BHC alone, those

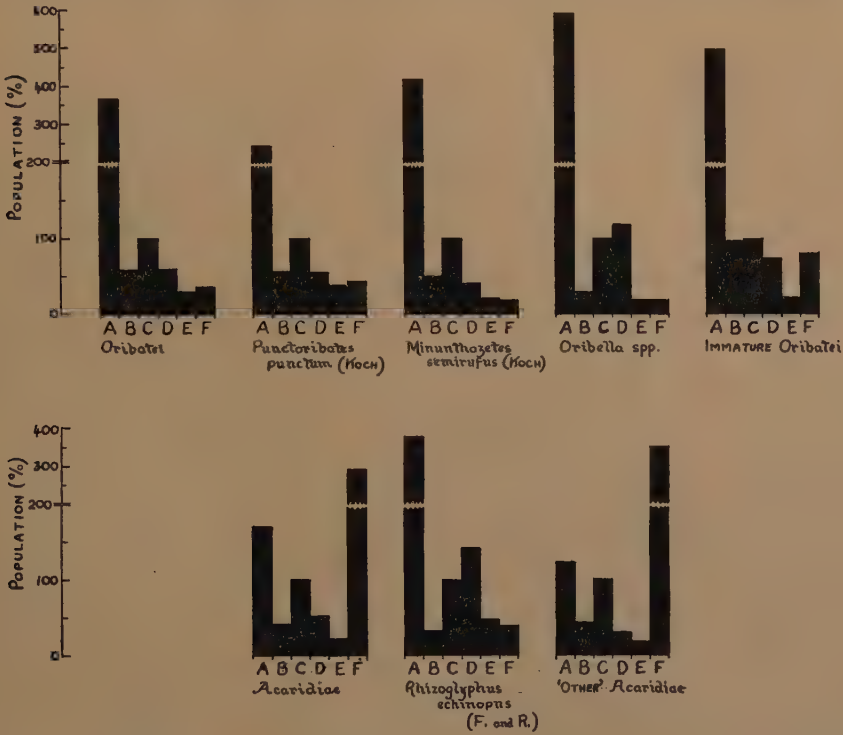


Fig. 2.—Overall effects of treatments, October 1951–October 1952. Oribatei and Acaridae. Other details as in fig. 1.

treated with both insecticides showed a further reduction only in the case of *M. semirufus*, but the DDT plus BHC/BHC difference was not significant. In respect of Mesostigmata, the lowest populations were observed in the plots receiving the mixed insecticides, the population so treated being significantly

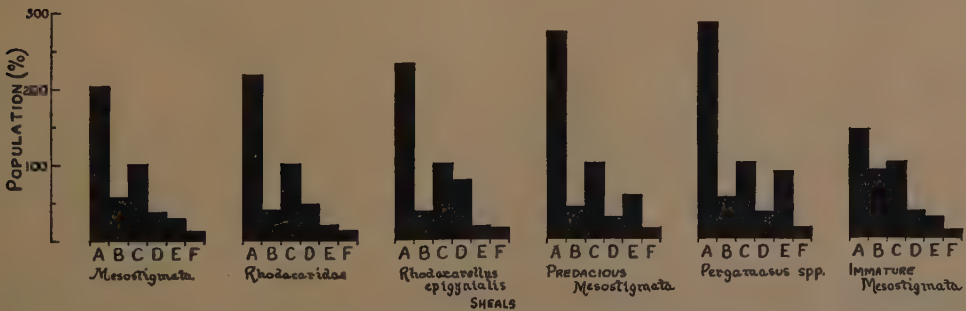


Fig. 3.—Overall effects of treatments, October 1951–October 1952. Mesostigmata. Other details as in fig. 1.

lower than the control. In the analyses of *Pergamasus* sp. and total observed predacious Mesostigmata (see page 814), the BHC-treated populations did not differ significantly from the controls, but the reductions in the comparison of BHC alone with DDT plus BHC were significant at the 0.01 and 0.05 probability levels, respectively.

TABLE III.

Results of analysis of data for October 1951–October 1952 (five occasions), based on square-root transformations of the original figures.

Group or species	(i) Undug	(ii) Fallow	(iii) Control	(iv) DDT	(v) BHC	(vi) DDT + BHC	(vii) F (treat- ments)	(viii) S.E.	(ix) F (treat- ment \times time)
Total Collembola	258.5	106.2	236.3	343.5	132.2	210.9	22.48	18.3	1.82
Total euedaphic Collembola	224.3	82.4	200.2	306.4	93.3	165.8	16.02	21.1	1.39
Total Tullbergiinae ..	135.7	55.0	114.0	238.1	67.2	123.3	11.32	19.4	1.49
<i>Tullbergia krausbaueri</i> ..	118.6	45.7	90.9	117.0	49.6	56.7	10.77	10.2	1.66
<i>Tullbergia crassispis</i> ..	29.5	14.6	42.7	167.7	28.0	95.9	4.19	28.6	—
Total <i>Onychiurus</i> spp. ..	93.9	26.6	87.9	129.1	29.4	59.9	4.57	18.7	—
<i>Isotomodes productus</i> ..	80.0	18.9	84.9	58.0	18.7	48.1	4.49	13.6	1.51
<i>Folsomia candida</i>	69.8	19.5	73.5	68.5	19.1	26.9	4.32	13.0	1.49
Total hemiedaphic Collembola	115.3	46.9	109.7	136.3	81.4	111.6	13.24	8.4	2.47
Total Oribatei	216.0	83.5	109.7	85.2	57.0	65.0	10.01	18.5	2.56
<i>Punctoribates punctum</i> ..	96.2	44.0	57.3	44.2	30.4	39.0	4.02	11.7	2.78
<i>Minunthozetes semirufus</i> ..	137.5	34.1	60.5	29.7	20.2	18.9	14.13	12.1	2.43
Total Oribella spp. ..	60.4	7.4	18.9	20.6	4.4	4.4	6.66	8.3	2.62
Total immature Oribatei	52.8	17.1	18.0	16.7	4.8	12.3	3.15	9.4	—
Total Acarididae	88.1	42.6	60.6	56.6	25.9	63.0	2.64	—	1.97
<i>Rhizoglyphus echinopus</i> ..	58.9	10.9	20.7	32.2	14.1	13.2	3.06	10.5	1.02
Total other Acarididae ..	39.9	34.8	40.0	29.5	12.5	53.1	1.34	—	1.65
Total Mesostigmata ..	158.7	82.1	111.5	64.3	56.0	30.6	18.89	10.5	1.56
Total Rhodacaridae ..	104.4	36.0	68.9	40.0	20.6	14.4	10.12	10.6	—
<i>Rhodacarellus epigynialis</i>	72.5	19.7	48.1	34.9	12.0	9.7	7.71	8.8	—
Total known predacious Mesostigmata ..	65.4	17.7	33.4	12.2	25.7	8.0	15.16	5.4	1.13
Total <i>Pergamasus</i> spp. ..	50.7	13.5	22.3	10.1	24.5	5.0	14.72	4.2	—
Total immature Mesostigmata	59.9	42.9	47.6	23.0	19.0	6.8	16.54	4.9	—

Columns (i–vi): Treatment totals.

Col. (vii): Values of variance ratio, F , for treatment comparisons (degrees of freedom, $n_1 = 5$, $n_2 = 15$). Significance levels:— $P = 0.05$, 2.90; $P = 0.01$, 4.56.

Col. (viii): S.E. of treatment totals. Values of $\sqrt{2t}$ for 15 d.f.:— $P = 0.05$, 3.0; $P = 0.01$, 4.2.

Col. (ix): Values of F for interaction of treatments with time. D.f., $n_1 = 20$, $n_2 = 60$. Significance levels: $P = 0.05$, 1.77; $P = 0.01$, 2.25.

(b) *The interaction of treatments with time.*—In a number of analyses, significant values of F were obtained for the interaction of treatments with time, indicating that the effectiveness of the treatments varied significantly according to the time of sampling. Where appropriate, therefore, the data were analysed

separately for each of the five occasions, and the more important results are depicted in figs. 4-6. This interaction is important in relation to the question of recolonisation, but it is important to note that, whilst the absence of a significant degree of recolonisation over this annual period is shown by a non-

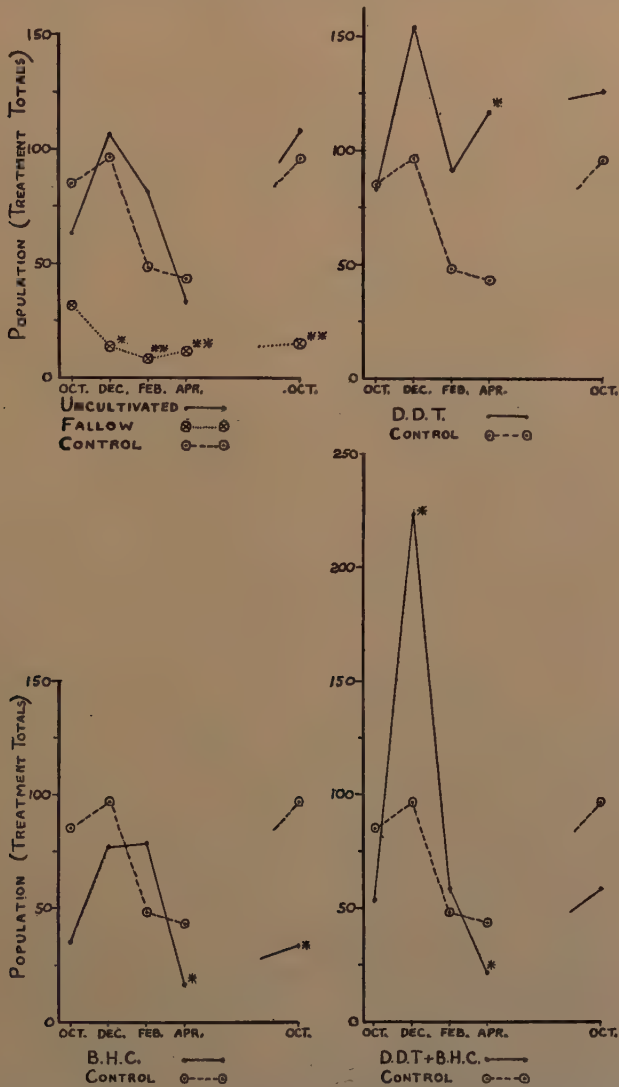


Fig. 4.—Interaction of treatments with time, October 1951–October 1952. Hemiedaphic Collembola. Points differing significantly from the control are indicated thus:—

$P = 0.05$ *
 $P = 0.01$ **
 $P = 0.001$ ***

significant interaction of treatments with time, the significance of the latter does not necessarily indicate the significance of the former, for other changes could influence the value of this mean square. Where the initial examination suggested

the possibility of recolonisation or further divergence, an assessment of the significance of these changes was made by analysing the annual rates of change of the populations. This was measured by the difference between the October

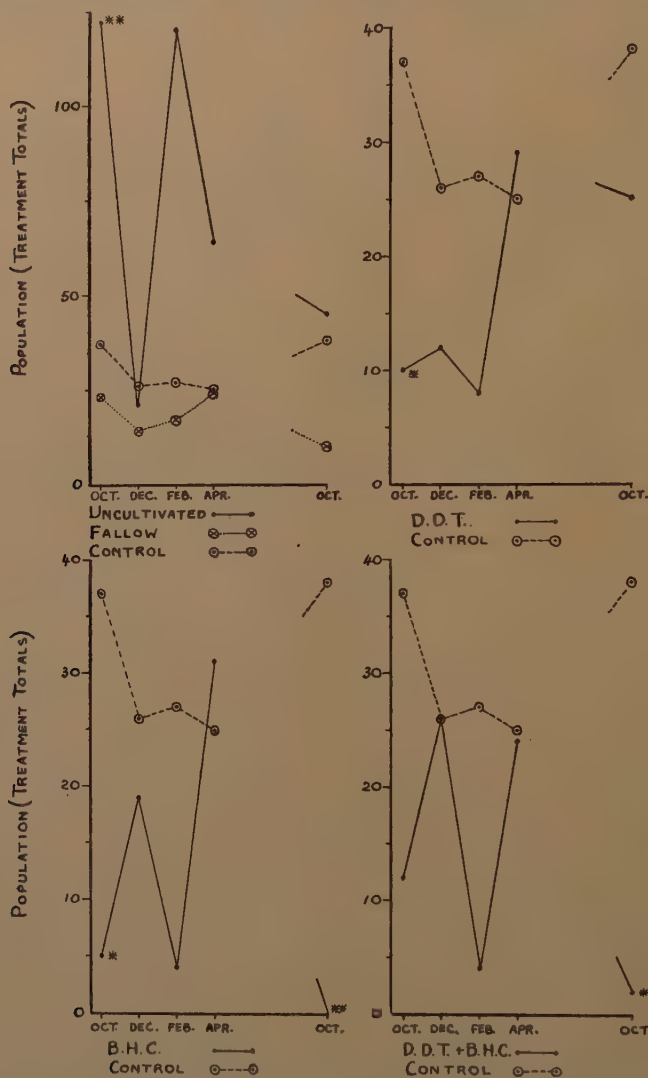


Fig. 5.—Interaction of treatments with time, October 1951–October 1952. *Puntoribates punctum*. Other details as in fig. 4.

1951 and October 1952 populations in each plot, and the significance of treatment differences was then assessed in an inter-plot analysis. Of the forms showing a significant interaction, the only species which recolonised to a significant degree was *Puntoribates punctum* where a recovery of the DDT-treated population was evident. It is important to note, however, that these examinations did not take account of any changes taking place between June and October 1951. In a number of cases, the differences which obtained in both October 1951 and October 1952 were non-significant, although on intermediate occasions marked

and significant differences were evident. An example of this is seen in the BHC-treated population of hemiedaphic Collembola. Obviously, the absence of a statistically significant difference does not in itself constitute a proof of similarity, so that the data in such cases must be regarded as inconclusive.

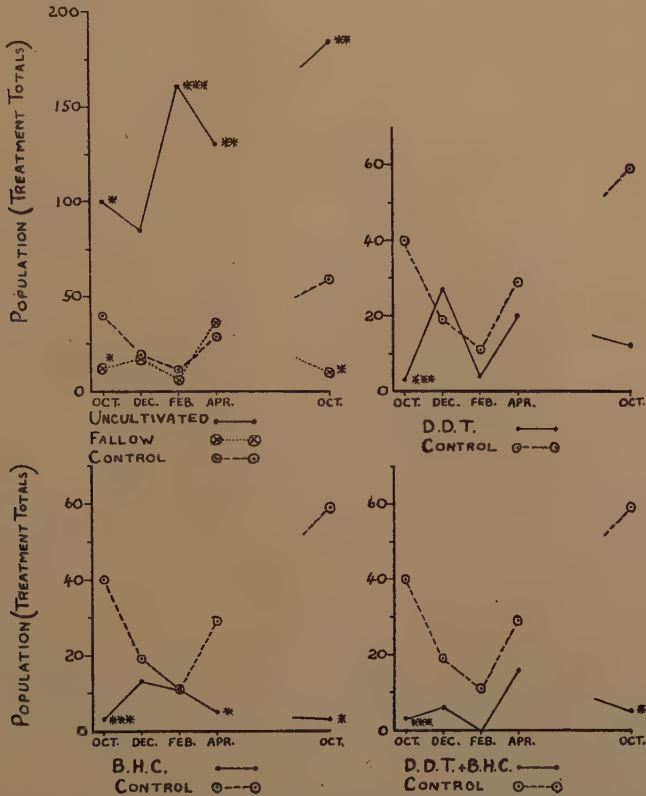


Fig. 6.—Interaction of treatments with time, October 1951–October 1952. *Minunthozetes semirufus*. Other details as in fig. 4.

The hemiedaphic Collembola were the only constituent group of "Total Collembola" showing a significant interaction of treatments with time. On no occasion were there significant differences between the uncultivated and re-seeded control populations of this group, but the fallow population was significantly lower than the control at all times except October 1951, when a non-significant reduction of 65 per cent. was evident. The increase of population associated with DDT was less marked than in the euedaphic forms, and, although significant in the overall analysis, in the separate examinations it was not evident in October 1951, and significant only in April 1952. In the case of the DDT plus BHC-treated population, a steep rise occurred between October and December 1951. On the latter occasion, the population so treated attained a level 130 per cent. higher than the control, the difference being significant at the 0.05 probability level. Subsequently, this population decreased, and was similar to the control in February, significantly lower than the latter in April, whilst in October 1952 it was 40 per cent. lower than the control, but the difference was not significant.

Although showing significant interactions, marked resurgences were not evident among the Oribatei. In relation to the effects of re-seeding, the interaction was due mainly to fluctuations in the uncultivated population, and particularly to the drop which occurred between October and December 1951. In *P. punctum*, the December population in the uncultivated soil was significantly lower than those which obtained in both October 1951 and February 1952. Again, the small difference which obtained between the uncultivated and control populations of this species in October 1952 was due mainly to a decrease in the uncultivated population, although this change in the uncultivated soil was not significant in the annual comparison. It was noted that in *Oribella* species the control population was low at all times, and there were no significant differences attributable to the insecticides. In October 1951 all but one of the insecticide-treated populations of the two dominant species, *P. punctum* and *M. semirufus* (figs. 5 and 6), were significantly lower than the control but, with some exceptions, the results for these two species on the intermediate sampling occasions were inconclusive. In all the cultivated plots many of the fluctuations were irregular in character, and the changing status of the treated populations was largely due to fluctuations in the control. The only significant difference attributable to insecticide treatment occurred in the April 1952 analysis of *M. semirufus*, when the BHC population was significantly lower than the control. In October 1952, significant differences attributable to BHC and to DDT plus BHC were again evident in both species, but the differences due to DDT were not significant. Only in *P. punctum* did the analysis of annual rates of change reveal a significant DDT/control comparison. The recovery of this species was first apparent in April 1952, when the DDT population was observed to be 16 per cent. greater than the control. Subsequently, the recovery was sufficiently well maintained to produce the significant change noted above.

Laboratory Observations.

With a view to obtaining information on the feeding habits of the dominant species, cultures of living animals were observed in the laboratory. These observations have been reported in greater detail elsewhere (Sheals, 1956) and for the purposes of the present paper it is sufficient to note that the following species of Mesostigmata (all common in the field) were seen to be active predators of Collembola and other small animals:—*Pergamasus runciger* Berl., *P. misellus* Berl., *Veigaia nemorensis* (Koch), *Digamasellus* sp., and *Hypoaspis aculeifer* (Can.). No positive information was obtained on the feeding habits of the RHODACARIDAE—the most numerous Mesostigmata in the soil studied—and whilst their morphology would suggest a predatory habit, direct observation failed to endorse this view.

Laboratory toxicity tests showed DDT to have no apparent effect on any of the Collembola examined, and even when the p,p' isomer was applied in prodigious quantities no toxic symptoms were observed. This substance, however, was found to be toxic in a varying degree to all the mites. All forms were susceptible to BHC, and Collembola were paralysed almost immediately when placed on a treated surface. In laboratory comparisons of the toxicity of BHC alone and DDT plus BHC on Collembola, there was no evidence of any antagonism between the two insecticides.

Discussion.

The influence of cultivation.

(a) *Re-seeding.*—In June 1951, cultivation caused a substantial reduction in the populations of all the major groups. At this time the uncultivated population was at a low level, and statistical significance was not established in all the

analyses. Thus, the significant standard of the reductions in the total Collembolan and total euedaphic Collembolan populations was rather short of the 0.05 probability level. Only one species appeared to increase (although the increase was not significant) as a result of re-seeding; this was *Isotomodes productus* (Axel.), a form reputed to be favoured by drier conditions (Gisin, 1943). In a number of cases the destructive action of cultivation was significantly more effective in relation to the population of the upper stratum. While this could be largely attributed to the virtual absence of the animals concerned in the lower stratum of all plots, in the dominant Oribatei there was a distinct tendency towards an increase in the lower soil of the re-seeded control. This was significant in *P. punctum*. It is suspected, however, that the coriaceous exoskeletons of Oribatei are slow to disintegrate in soil, and, although the remains of obviously long-dead animals were not included in the counts, this factor may have influenced the June assessments. With this qualification, the results suggest that, although considered to be predominantly hemiedaphic in character (Strenzke, 1952), unlike the hemiedaphic forms of Collembola, the Oribatei are also able to live in the lower soil.

There can be little doubt that the majority of the Collembola recovered quickly from this initial decimation. In October 1951, all the dominant species except *Tullbergia krausbaueri* (Börn.) were observed to be more abundant in the control; and in December *T. krausbaueri* was more abundant in the re-seeded plots. In the overall analyses of the October 1951–October 1952 data, there were no significant differences between the uncultivated and re-seeded control populations. In the hemiedaphic forms, where the interaction of treatments with time was significant, further analyses revealed that at no time during this period was there a significant difference attributable to re-seeding. Nevertheless non-significant differences were observed, and some of these are worthy of note. In both euedaphic and hemiedaphic forms the seasonal fluctuation was observed to be rather more violent in the control, and particularly so in relation to the decrease of population which occurred between December and February. Interaction of this type was not contrary to expectation, for the thick "mat" of vegetation and the surface concentration of moist organic matter in the uncultivated plots would almost certainly have constituted a more effective buffer against changing climatic conditions than the thin sward of the control. Again, except in December 1951, *T. krausbaueri* was less numerous in the control plots, and, despite the absence of statistical significance, the overall reduction of 44 per cent. in this species over the October 1951–October 1952 period cannot be ignored. Thus, while all the Collembola made an initial recovery from the effects of cultivation, there was evidence to suggest that after December 1951 the divergence between the control and uncultivated populations was renewed, and particularly in respect of *T. krausbaueri*.

The Oribatei did not recover in this way. In the overall comparison of the October 1951–October 1952 results, the uncultivated population was in all cases significantly higher than the control, the average "uncultivated" population of these mites being $3\frac{1}{2}$ times that of the re-seeded control plots. In October 1951 all the Oribatei analysed were significantly less abundant in the control, and on subsequent occasions the approximations of the control and uncultivated populations were temporary, and due almost entirely to seasonal changes in the uncultivated population. In October 1952 *P. punctum* was the only species in which no significant difference was evident between the control and uncultivated populations. With regard to the total population of Oribatei in the uncultivated and control plots, the difference noted in October 1952 was almost identical with that in October 1951. Thus, with the exception of *P. punctum*, the destructive influence of cultivation and re-seeding on the population of Oribatei in the upper 6 in. of soil remained apparent 17 months after sowing.

In relation to Acaridae, conclusive results were obtained only for *Rhizoglyphus cchinopus*. In June 1951, cultivation and re-seeding induced a non-significant reduction of this species, but in the overall comparison of the data obtained on subsequent occasions the uncultivated population was 277 per cent. greater than that in the re-seeded soil. This difference was significant, and there was no significant evidence of recovery.

The Mesostigmata also showed no definite evidence of recovery. In the comparison of the October 1951–October 1952 data, all the species were significantly less abundant in the re-seeded plots, with the exception of *Rhodacarellus epigynialis* Sheals and immature Mesostigmata.

Thus, both Collembola and Acarina were initially reduced by cultivation and whilst Collembola made a rapid recovery, the Acarina did not. Probably this differential rate of recovery was due, in part, to the greater capacity of Collembola for rapid reproduction. In fact, the seasonal fluctuation of these insects is apparently due to periods of partial destruction by adverse climatic conditions followed by phases of rapid recolonisation. Hence, Collembola would be expected to make a more rapid recovery than the Oribatei, many of which are known to have long life-cycles (*vide* Michael, 1884–88; Rooseboom quoted by van der Drift, 1951; Cleat, 1952). The prolonged and significant reduction of predacious Mesostigmata could be explained in terms of the Volterra-Lotka theories. A comparison in February 1952 indicated that there was little difference in the total amount of organic matter present in the upper 6 in. of the uncultivated and re-seeded soil. Nevertheless, qualitative differences of some magnitude must have obtained, for cultivation would have caused a more even distribution of organic material in the profile, so that the near-surface concentration of plant residues (the habitat of the majority of saprophagous and mycetophagous species in soil) would be less pronounced in these plots. The prolonged reduction of the population can thus be associated with a reduction in the size of the habitat. Summing up, there were few qualitative differences between the micro-arthropod communities of the uncultivated and re-seeded soil, for, apart from certain Acarina of infrequent occurrence, the species represented in the uncultivated areas were also found in the re-seeded plots, and *vice versa*. The main quantitative difference attributable to re-seeding was a reduction in the Acarine population, especially Oribatei, although there was also an indication of a prolonged reduction of certain Collembola, particularly *T. krausbaueri*. These differences were apparently due to the more even vertical distribution of organic debris in the re-seeded soil than to the amount of organic material present.

(b) *Fallowing*.—In June 1951, during the early stages of establishment of the newly sown sward, the differences between the control and fallow populations were not well marked, but in the October 1951–October 1952 comparisons the Collembolan populations of the fallowed soil showed drastic reductions. With the exception of the population of *Tullbergia crassiuspis* Gisin, these differences were significant. In the case of the mites, the re-seeding operation caused a prolonged reduction so that the further effect of fallowing was less marked, and statistically significant reductions were infrequent. As measured by loss on ignition there was little difference in the organic matter content of the upper 6 in. of soil of any of the plots, so that, as in the re-seeded control, it is probable that the reductions were largely due to changes brought about by the disruption of the moist debris of the upper soil, conditions which were prolonged and accentuated by the absence of a cover crop.

The influence of insecticides.

Owing to the destructive influence of cultivation on a population near its seasonal minimum, the effects of the insecticide treatments were not well marked in June 1951. For this reason, the responses of the population have to be

discussed mainly in the light of the information collected on the five occasions during the year October 1951–October 1952. In the overall comparison of these data, severe reductions of Collembola and Acarina were evident in the plots treated with BHC. Of special interest are the responses of the population to the DDT and DDT plus BHC treatments. The former caused a reduction of the Acarine population, but Collembola increased markedly as a result of treatment with this insecticide. The average Collembolan population of the DDT plots over the year was 110 per cent. higher than that in the control, and this difference was highly significant statistically. Similar increases were evident in the populations of many of the constituent groups and species. The greatest increase was that of *T. crassiscuspis*, to the extent of 15 times that of the control.

The response of Collembola to the mixture of both insecticides indicated that the presence of DDT reduced the destructive influence of BHC on these insects. In many cases there was little difference between the population treated with the mixed insecticides and the control, while in the analyses of total Collembola, and total euedaphic Collembola, the DDT plus BHC population was significantly higher than that treated with BHC but significantly lower than that treated with DDT alone. This trend was apparent in all Collembola, for, in every case, the DDT plus BHC population was intermediate in density when compared with those receiving the two insecticides separately.

Under the conditions of the laboratory tests, the mixed insecticides and BHC alone were equally toxic to Collembola in isolation. It is unlikely, therefore, that the field result was due to chemical or physiological interactions. While there was some slight, non-significant evidence of its occurrence among the mites in populations of some Cryptostigmata, evidence of a response opposite in character was obtained in respect of Mesostigmata. In the overall comparison, the populations of the Mesostigmata groups and species were in all cases lower in the DDT plus BHC plots than in either of the plots receiving these insecticides separately. Statistically, the DDT plus BHC-population of these mites was in all cases significantly lower than the control, and, in the analyses of total observed predacious Mesostigmata and *Pergamasus* spp., was also significantly lower than the population receiving BHC alone.

In many previous studies resurgences of this type have been attributed to the destruction of predators and parasites by the materials employed, and in a number of investigations (*e.g.*, Lord, 1949, 1949–50), this conclusion has been supported by evidence of reduced populations of carnivorous species. Resurgences of this type can of course, be expected on purely theoretical grounds. In a mathematical thesis, Volterra (1928) enunciated the "law" of the disturbances of averages, stating that, in a community of two species (one a predator and the other its prey) if individuals are uniformly destroyed in proportion to their number, the average population of the prey will increase, and that of the predator will diminish. Hence, on this basis, even when predator and prey are equally susceptible, the prey would eventually be favoured by insecticide treatments. When the prey is less susceptible the resurgence should, therefore, be accentuated.

In the present investigation there is abundant evidence to indicate that the significant increase of Collembola in the DDT-treated plots was due to a reduction of predatory pressure, and particularly that of the Mesostigmata. This evidence can be recounted as follows:—

- (a) Laboratory observations showed that at least five species of Mesostigmata commonly occurring in the field preyed actively on Collembola.
- (b) Laboratory tests showed that while Collembola were completely unaffected by DDT, even at the highest concentrations, this substance was definitely toxic to all the Mesostigmata examined.
- (c) In the field, the total population of Mesostigmata was significantly reduced

by DDT, as also was the total population of the five species observed to be predacious.

Other predacious organisms, particularly STAPHYLINIDAE, are known to feed on Collembola (MacLagan, 1932; Weis-Fogh, 1948). In the laboratory, Staphylinid species were seen to be highly susceptible to DDT, but they were not collected in sufficient numbers to facilitate a quantitative assessment of their response to this insecticide in the field.

The response of Collembola in the plots receiving the mixed insecticides is not only consistent with this explanation but provides supporting evidence. Thus, when compared with the population treated with BHC alone, the residual population of the DDT plus BHC plots would have been favoured by the additional protection against predators afforded by DDT, for the population of predacious Mesostigmata in the DDT plus BHC plots was significantly lower than that in the plots treated with BHC alone. Thus, in every comparison, the presence of DDT was associated with an increase of Collembola and a decrease of Mesostigmata. The only cases where significant reductions of predacious Mesostigmata were not accompanied by an increase of Collembola were in the comparisons of the uncultivated and re-seeded control, and re-seeded control with fallow plots, and here the reduction of predators was accompanied by major physical changes in the environment.

Thus, the bulk of the evidence in the present investigation supports the view that the resurgences of Collembola were due to a reduction of predatory pressure. Whilst most workers have attributed phenomena of this kind to similar causes, other factors have also been suggested as being contributory. Hueck & others (1952) observed that low concentrations of DDT caused an increase in the oviposition rate of Fruit Tree Red Spider (*Metatetranychus ulmi* (Koch)). In some experiments this increase was significant statistically, and at high rates a toxic effect was apparent. Von Baudissin (1952) found that after an initial toxic effect lasting for about two weeks, treatment with DDT plus BHC caused an increase in the population of soil Acarina and Collembola. The increase was not well marked, and the investigation did not include observations on the effect of DDT alone, neither were predatory mite-populations assessed. Von Baudissin conjectured that this increase was due to a chemotactic stimulation by residual quantities of DDT, although no evidence was advanced to support this explanation. Richter (1953) also observed an increase in DDT plus BHC-treated populations of Acarina and Collembola in forest soils, and he subscribed to the explanation offered by von Baudissin. In the present study an experiment in which the responses of Collembola to DDT were observed in predator-free cultures produced negative results, but owing to the great variation which obtained, these results were inconclusive. There are, however, other grounds to suppose that Collembola are not indirectly stimulated by DDT. Davis (1953), in experiments with *Tetranychus telarius* (L.) (cited as *T. multisetis* McG.), observed that, shortly after contact with DDT, the mites became highly active and moved over greater distances than untreated individuals. The treated individuals became widely scattered in their habitat and this dispersion resulted in a higher reproductive potential and hence in an earlier attainment of the asymptotic population. Hence, the increased reproduction in isolated colonies of Tetranychid mites under the influence of DDT could be attributed to an irritant effect of sub-lethal dosages. In this way, the evidence of Davis indicates that the effect of DDT on the reproduction rate of the mites is indirect, and related to density factors, whilst the evidence of Hueck & others, although not completely inconsistent with this explanation, suggest a response of a physiological nature. The possibility of a reaction of this type being partly responsible for the increase of Collembola in the present study cannot be completely eliminated, but the available evidence is opposed to this view. Observations on

Collembola in contact with DDT showed their reactions to be quite unlike those described for the TETRANYCHIDAE; for the animals showed no definite signs of increased activity, neither was there evidence of toxicity even at prodigious dosages.

The possibility of the increase of Collembola being due to a suppression of competition for food and space can also be considered, the potential competitors being the Acaridiae and Oribatei.

Analyses of Acaridiae revealed no significant responses attributable to insecticide treatments, and, although a non-significant reduction of the three species comprising "Other Acaridiae" was apparent in the DDT-treated plots, *Rhizoglyphus echinopus* on the other hand was seen to be more abundant in these plots than in the control. Thus, there was no consistent association of low Acarid with high Collembolan populations, and, therefore, no evidence of competition between the two groups.

With regard to Oribatei, most of the evidence is consistent with the view that these mites exerted little influence on Collembola. In the first place these mites are considered to be predominantly hemiedaphic in character (Strenzeke, 1952). Hence, it is unlikely that they had any marked influence on the euedaphic Collembolan populations, which in the present study were most responsive to the DDT treatment. Again, in the overall analyses, the reductions of Oribatei in the DDT plots were not significant, and in the separate analyses the effect of DDT was not always well marked. Moreover, in the comparison of the plots treated with BHC and those receiving both insecticides, the significant increases of Collembola were not accompanied by significant reductions of Oribatei. On a number of occasions these mites were actually more abundant in the plots receiving both insecticides.

Although the most marked associations were those between Collembola and the Mesostigmata known to be predacious, it is also important to consider the RHODACARIDAE—the dominant group of the Mesostigmata—in relation to these insects. The reaction of these mites to DDT was not significant, but their potential influence cannot be discounted, for the trends of their populations in both the DDT and DDT plus BHC plots were similar to those of the known predators. These are amongst the few mites which are found in the lower soil. Both Frenzel (1936) and Willmann (1935, 1936) noted this, and not only do the June results subscribe to this view, but these mites were found by the writer to have a deep distribution in other soils in Scotland (Sheals, 1956). The food habits of these mites are not known, but it is probable that they exert some influence on such deep-living Collembola as the TULLBERGIINAE either as predators or as competitors for food.

In relation to the problems posed by vertical distribution, Weis-Fogh (1948) observed that the larger species of the Mesostigmata were predominantly near-surface dwellers. Similarly, in Glasgow, the data collected in June 1951 showed that the Mesostigmata, other than the RHODACARIDAE, were more abundant in the upper soil. The smallest of the Mesostigmata known to be predacious was *Digamasellus* sp. This species did not occur in sufficient numbers in June 1951 to provide useful evidence on its vertical distribution, but in the soil of an upland pasture it was found in considerable numbers below the 1½-in. level, and was not uncommon below the 3-in. point where it occurred with RHODACARIDAE and TULLBERGIINAE. Thus, this species at least is capable of penetrating the deeper soil in search of its prey.

In the euedaphic Collembolan population, the response to the insecticide treatments was relatively constant during the year October 1951–October 1952, and significant interactions of treatments with time were revealed only in the analyses of populations of the near-surface dwelling groups, *viz.*, hemiedaphic Collembola and Oribatei. In relation to the question of recolonisation by these two groups,

the only species which (while showing a significant response to an insecticide treatment in October 1951) also produced significant evidence of recovery in October 1952 was *P. punctum*. This species recolonised the DDT plots to a significant degree in the annual comparison. In both the dominant Oribatei, the BHC- and DDT plus BHC-treated populations were significantly lower than the control in October 1952.

In the hemiedaphic Collembola, the DDT-treated population was similar to the control in October 1951. On all other occasions it exceeded the control, but significantly so only in April 1952. An interesting trend was evident in the BHC-treated population of this group, which showed a non-significant reduction of 60 per cent. in October 1951, and which thereafter rose so that in February it exceeded the control (non-significantly). This population then dropped and was significantly lower than the control in April and October 1952. It is probable that the temporary recovery of this population was due to the insecticide being leached into the deeper soil by precipitation during the autumn and winter. The subsequent drop, although surprising, is not devoid of explanation. The efficiency of BHC as a soil insecticide is related in part to its volatility; and, during the spring, rising soil temperatures may have caused an increased production of toxic vapour. The DDT plus BHC-treated population of hemiedaphic Collembola showed a non-significant reduction of 37 per cent. when compared with the control in October 1951. This population then rose steeply, and in December became significantly higher than the control (by 130%). This autumn increase was probably facilitated by the diminished toxicity of BHC due to leaching and by the protection against predators afforded by both insecticides.

Thus, when incorporated with the soil, both DDT and BHC cause profound quantitative changes in the micro-arthropod community. The effect of BHC is sufficiently marked and persistent to warrant some concern, for it seems reasonable to suppose that the drastic and prolonged reduction of saprophytic populations might have adverse repercussions on soil fertility. On the other hand, the study has also shown that treatment with these materials constitutes a useful technique for investigating the inter-relationships of animals in the field.

Summary.

The effects of cultivation and treatments with DDT and BHC on soil Collembola and Acarina were investigated. Cultivation resulted initially in a drastic reduction of the micro-arthropod population and in the fallow plots this reduction persisted. Re-seeding resulted in rapid recolonisation by Collembola, but the populations of Oribatei and Mesostigmata remained at a low level over a period of 17 months after sowing. Treatment with BHC caused a heavy reduction of most micro-arthropoda. DDT caused reductions of mites, particularly Mesostigmata, but there was a marked increase of Collembola in the plots so treated. Significant increases of Collembola and significant reductions of predacious Mesostigmata were also noted in the comparison of plots treated with a DDT plus BHC mixture with those receiving BHC alone. The increase of Collembola was thus associated with a reduction of predatory pressure. In most cases, the effects of the treatments that included BHC were apparent 17 months later, but a temporary recovery of near-surface dwelling Collembola occurred in the BHC-treated plots in February 1952. Of the groups and species significantly affected by insecticide treatments in October 1951, only in one case did the data of October 1952 produce significant evidence of recolonisation. This recovery was noted in the DDT-treated population of *Punctoribates punctum* (Koch).

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References.

- VON BAUDISSIN, F. Graf. (1952). Die Wirkung von Pflanzenschutzmitteln auf Collembolen und Milben in verschiedenen Böden.—Zool. Jb., (Abt. Syst.), **81**, pp. 47–90.
- CLEAT, N. D. (1952). Growth in the laboratory of economically important Oribatid mites.—Nature, Lond., **169**, pp. 280–281.
- DAVIS, D. W. (1953). Some effects of DDT on spider mites.—J. econ. Ent., **45**, pp. 1011–1019.
- DEBACH, P. & BARTLETT, B. (1951). Effects of insecticides on biological control of insect pests of citrus.—J. econ. Ent., **44**, pp. 372–383.
- VAN DER DRIFT, J. (1951). Analysis of the animal community in a beech forest floor.—Tijdschr. Ent., **94**, pp. 1–168.
- FRENZEL, G. (1936). Untersuchungen über die Tierwelt des Wiesenbodens.—130 pp. Jena, Fischer.
- GISIN, H. (1943). Ökologie und Lebensgemeinschaften der Collembolen im Schweizerischen Exkursionsgebiet Basels.—Rev. suisse Zool., **50**, pp. 131–224.
- GRIGOR'EVA, T. G. (1952). The action of hexachlorane introduced into the soil on the soil fauna. [In Russian.].—Dokl. vsesoyuz. Akad. sel.-khoz. Nauk Lenina, **17**, pp. 16–20. (Rev. appl. Ent., (A) **41**, p. 336.)
- HUECK, H. J., KUENEN, D. J., DEN BOER, P. J. & JAEGER-DRAAFSEL, E. (1952). The increase of egg production of the Fruit Tree Red Spider Mite (*Metatetranychus ulmi* Koch) under influence of DDT.—Physiol. comp., **2**, pp. 371–377.
- KELLER, H. (1951). Über die Wirkung einer Bodenbegiftung mittels DDT- und Hexa-Mitteln auf die Kleinarthropoden, insbesondere Collembolen.—Naturwissenschaften, **38**, pp. 480–481.
- LORD, F. T. (1949). The influence of spray programs on the fauna of apple orchards in Nova Scotia: II. Oystershell Scale, *Lepidosaphes ulmi* (L.).—Canad. Ent., **79**, pp. 196–209.
- LORD, F. T. (1949–50). The influence of spray programs on the fauna of apple orchards in Nova Scotia: III. Mites and their predators.—Canad. Ent., **81**, pp. 202–214, 217–230.
- LOTKA, A. J. (1925). Elements of physical biology.—460 pp. Baltimore, Williams & Wilkins.
- MACLAGAN, D. S. (1932). An ecological study of the "Lucerne Flea" (*Smynturus viridis*, Linn). I & II.—Bull. ent. Res., **23**, pp. 101–145, 151–190.
- MARTIN, H. & WAIN, R. L. [1945]. The qualitative examination of insecticidal properties. Progress report, 1944.—Rep. agric. hort. Res. Sta. Bristol, 1944, pp. 121–140.
- MICHAEL, A. D. (1884–88). British Oribatidae.—2 vols. London, Ray Soc.

- RICHTER, G. (1953). Die Auswirkung von Insektiziden auf die terricole Makrofauna. (Quantitative Untersuchungen begifteter und unbegifteter Waldböden.)—NachrBl. dtsh. PflSchdienst, Berlin, N.F. **7**, pp. 61–72.
- SALT, G. & HOLLICK, F. S. J. (1944). Studies of wireworm populations. I. A census of wireworms in pasture.—Ann. appl. Biol., **31**, pp. 52–64.
- SHEALS, J. G. (1956). Notes on a collection of soil Acari.—Ent. mon. Mag., **92**, pp. 99–103.
- STRENNKE, K. (1952). Untersuchungen über die Tiergemeinschaften des Bodens: Die Oribatiden und ihre Synusien in den Böden Norddeutschlands. Lief. 1–2.—Zoologica, Stuttgart, **37**, pp. 1–173.
- VOLTERRA, V. (1928). Variations and fluctuations of the number of individuals in animal species living together.—J. Cons. int. Explor. Mer, **3**, pp. 3–51. (Translation by Wells, M. E. in Chapman, R. N. (1931). Animal ecology, pp. 409–448. New York, McGraw Hill.)
- WEIS-FOGH, T. (1948). Ecological investigations on mites and Collembolus in the soil.—Nat. Jutlandica, **1**, pp. 135–270.
- WILLMANN, C. (1935). Über eine eigenartige Milbenfauna im Küstengrundwasser der Kieler Bucht.—Schr. naturw. Ver. Schl.-Holst., **20**, pp. 422–434.
- WILLMANN, C. (1936). Neue Acari aus schlesischen Wiesenböden.—Zool. Anz., **113**, pp. 273–290.
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